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Banana Nutrition

Function and Processing Kinetics

Edited by Afam I. O. Jideani and Tonna A. Anyasi

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Meet the editors

Afam is a professor of Food Science and Technology at the University of Venda, South Africa. He obtained his PhD from the University of Leeds, UK. He became a full professor in 1999 before becoming the Director of Research and Development at the National Food Technology Research Centre, Botswana (2006). While in Botswana he briefly chaired the Food Legislation and Advisory Committee of the National (Botswana) Food Control Board and attended the 2008 Geneva Codex Alimentarius Commission as part of Botswana delegation. He is a National Research Foundation (South Africa) rated researcher with a Google Scholar h-index 20 and orcid id: 0000-0002-9122-8697. He has 148 publications in scientific journals, books, and book chapters. He is a fellow of the Nigerian Institute of Food Science and Technology (NIFST) and a professional member of the following scientific bodies: (i) South African Association of Food Technologists (SAAFoST), (ii) American Association of Cereal Chemists International (AACCI), (iii) Institute of Food Technologists (IFT), (iv) the ISEKI Food Association (IFA) where he is the current South African country representative, and (v) member of the Education Committee of the International Union of Food Science and Technology (IUFoST).

Tonna Anyasi obtained his doctoral degree in Agriculture (Food Science and Technology) from the University of Venda, South Africa, where he also conducted his postdoctoral studies. His research interests include studies on antioxidants, bionutrients, phytochemicals, and *in vitro* digestibility of starch in fruits, vegetables, roots, and tuber crops. He has published several journal articles and book chapters and serves as a reviewer for Elsevier, Springer Nature, Wiley, and American Chemical Society journals. He is currently an Early Career Scientists Section member of the International Union of Food Science and Technology, Toronto, Canada; a member of the Institute of Food Technologists Illinois, USA; as well as a professional member of the South African Association for Food Science and Technology.

Contents

Preface

Bananas are one of the top ten world food crops. This book, "Banana Nutrition – Function and Processing Kinetics", covers nutritional topics on the banana plant and fruit. It includes the following important chapters: (i) Introductory chapter on banana nutrition – function and processing kinetics; (ii) Pharmacological activities of banana; (iii) Banana bioactives: absorption, utilization, and health benefits; (iv) Banana pseudo-stem fiber: preparation, characteristics, and applications; (v) Banana drying kinetics; and (vi) Integrating text mining and network analysis for topic detection from published articles on banana sensory characteristics.

The introductory chapter focuses on the transgenicity of banana. Cultivation is affected by various diseases with the most serious being the Bunchy top disease caused by the Banana bunchy top virus (BBTV) and Fusarium wilt caused by the virulent fungus, *Fusarium oxysporum* f. sp. *cubense* tropical race 4 (TR4). Advances such as gene-editing have helped create plants that produce higher yields to meet the growing demand along with higher nutritional content. The purposes of the transgenic banana include enhanced fruit and value-added traits, pharmaceutical/ medicinal purpose, improved productivity, health, and nutrition. Some target traits in the transgenic banana include drought tolerance, disease resistance, stress and insect resistance, vitamin A content, color change, and vaccine production. The chapter highlights current research areas and findings on banana improvement using tissue culture and transgenic technology.

The chapter on "Pharmacological activities of banana" deals with the significance of the banana in traditional medicine and the pharmaceutical industries. Different chemical constituents such as apigenin glycosides, myricetin-3-O-rutinoside, kaempferol-3-O-rutinoside, dopamine, and serotonin have been reported in different parts and varieties of banana. The presence of carbohydrates, proteins, and flavonoids make bananas useful in both nutrition and therapeutics. The chapter discusses the essential information about the banana, including its varieties, distribution, pharmacological actions, and its relevance in the pharmaceutical industry. The information will be beneficial for researchers to further harness the robustness of this fruit in controlling many diseases and modification of drugs.

The chapter on "Banana bioactives: absorption, utilization, and health benefits" shows that the fruit is rich in carbohydrates, minerals, and vitamins and is of great economic value. To increase the postharvest shelf-life of banana fruit, an appropriate postharvest handling procedure needs to be adopted to maintain the freshness of the produce. During the peak banana season, the fruit can be converted into intermediate products such as puree, concentrate, and ready-to-use forms such as chips and juices. Conversion into value-added products can reduce the huge amount of postharvest losses. Various processing methods converting this fruit into value-added products are highlighted.

The chapter on "Banana pseudo-stem fiber: Preparation, characteristics, and applications" highlights that almost all the parts of this plant, i.e. fruit, leaves, flower bud, trunk, and pseudo-stem can be utilized. It discusses the production of banana pseudo-stem fiber, which includes plantation and harvesting; extraction of banana pseudo-stem fiber; retting; and degumming of the fiber. Several potential applications of this fiber are also mentioned, such as to fabricate rope, place mats, paper, cardboard, string thread, tea bags, high quality textile materials, absorbent, and polymer/fiber composites.

The chapter on “Banana drying kinetics” deals with the highly perishable fruit, requiring preservation in some form. Useful processes (natural and artificial) in the preservation of banana fruits are the focus of this chapter. Minimal processing, refrigeration, and dehydration or drying processes are the highlight of this chapter, including the different advantages and shortcomings. The chapter covers drying kinetics of banana, including prediction of drying behavior, and optimization of drying parameters. The chapter assesses the models of drying kinetics in predicting the drying behavior and in optimizing the drying parameters of banana fruits.

The final chapter is on “Integrating text mining and network analysis for topic detection from published articles on banana sensory characteristics”. The chapter reviews published articles (28) from the PubMed database on banana sensory characteristics from 2002 to 2018, showing that the frequency of publication increased significantly from 3.6% in 2002 to 17.9% in 2011, decreased in 2012 and 2013, but has shown a steady increase from 2014. Data were mined to detect the topic of discussion using the KNIME software. The texts were tagged with the OSCAR chemical named entity and preprocessed by filtering and stemming, thereafter the topic of discussion detected with the Latent Dirichlet Allocation and term co-occurrence determined using KNIME data mining software. The co-occurrence terms were converted to node adjacency matrix and imported into Gephi Graph Visualisation and Manipulation software version 0.02. Network statistics such as modularity class, degree centrality, betweenness and closeness centrality were estimated. The majority of the OSCAR tagged words (50.8%) were chemical compounds, 47.3% were ontology terms, 1.2% were reaction names, and 0.7% were chemical adjectives. The directed network consisted of 53 nodes and 904 edges. There were four modularity classes; the base class and class 1 each consisted of 20.7%, class 2, 41.5%, and class 3, 17.0% of the nodes. The terms with high betweenness centrality (>45) were: accept (139), fruit (92), analysis (73) [class 0], coat (125), food (60), composite (47) [class 1] and banana (192) [class 3]. Three topics each consisting of five words were detected from the documents. This chapter provides details of each topic.

The various chapters contain recent advances in banana biotechnology that will appeal to farmers, plant breeders, food industry, food science programs, investors, and consumers. The information will be beneficial for researchers to further harness this crop in controlling many diseases and especially non-communicable nutrition-related human illnesses. It therefore contains substantial scientific information written in a form that is easy to understand. I appreciate the contributors of the chapters as well as the sources of funding for each chapter.

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Chapter 1

Introductory Chapter: Banana Nutrition - Function and Processing Kinetics

Afam I.O. Jideani

1. Introduction

Bananas (*Musa* spp.) are typical climacteric fruit with rich nutrient contents which are considered as a healthy fruit. They are one of the top 10 world food crops contributing to cash and food crop in the tropics and subtropics. Bananas are important in nutrition, therapeutics, traditional medicine and the pharmaceutical and food industries. The different chemical constituents like apigenin glycosides, myricetin-3-O-rutinoside, kaempferol-3-O-rutinoside, dopamine and serotonin have been reported in different parts and varieties of banana [1]. Pharmacological actions of bananas have been seen such as antiulcer, antimicrobial and antioxidant activities. Almost all the parts of this plant, i.e. fruit, leaves, flower bud, trunk, pseudo-stem can be utilized. The book highlights the extraction of banana pseudo-stem fibre and retting; as well as degumming of the fibre with the characteristics and potential application of banana pseudo-stem fibre, including morphological, physical, mechanical, durability, degradability, thermal, chemical, and anti-bacterial properties. Several potential applications of this fibre highlighted are the use of this fibre to fabricate rope, place mats, paper cardboard, string thread, tea bag, high quality textile materials, absorbent and polymer/fibre composites.

Pre- and postharvest technologies invariably affect the carbohydrates, minerals, vitamins and other composition like the bioactives of plant foods. To increase the postharvest shelf life and quality of banana fruit, appropriate postharvest handling procedure ensures the freshness of the produce considering effects of climate change on crops. The conversion into intermediate and other products ensures the versatility in value addition. Also, conversion into value added products can reduce huge amount of postharvest losses. The aspects of transgenic technology in banana complement the advances in banana biotechnology, giving rise to product development strategies. As highly perishable fruit, bananas require robust preservation processes (natural and artificial) including minimal processing, refrigeration and dehydration (both thermal and nonthermal drying processes). The models of drying kinetics in predicting the drying behaviour and in optimising the drying parameters of banana fruits are all important food engineering applications. Also, integrating digitalisation systems into banana value chain/processing will benefit the banana industry as Siemens recently created consistent automation with its digital enterprise. In addition, integrating text mining and network analysis of published articles on banana sensory characteristics reveal factors such as chemical additives, ontology and other intrinsic attributes needed by food processors in meeting the expectation of consumers. The food industries are poised to improve customers' health and expectation on nutritious food products. The advocacy by some food professionals about the benefits of plant foods is seen in the focus of key food companies on health food and products. Recently in 2018, Cargill addressed health issues for food manufacturers at Gulfood Manufacturing: heart health, for example, its latest CoroWise® Plant Sterols and Prolía® Soy Flour are fast gaining popularity among food manufacturers. Most of these innovations are also backed by an FDA health claim.

Research investigations have continued on the nutritional benefits of banana; such that scientists have created 'vitamin-A rich fruit that could save hundreds of thousands of children's lives'. In the Newsweek of July 10, 2017 was the publication by Hannah Osborne 'vitamin-A rich GMO banana [2], which could fight malnutrition in Africa, ready for field trials'. Scientists in Australia have created golden-orange-fleshed bananas rich in pro-vitamin A that could save the lives of children who die from a deficiency of this vitamin every year. The 'biofortified' bananas were developed by taking genes from a species of banana from Papua New Guinea, which is high in provitamin A but only produces small bunches, and combined it with that of a the high-yielding specie, Cavendish banana. Provitamin A is converted by the body into vitamin A. In research findings published in Wiley's Plant Biotechnology Journal, the team presented results from proof of concept field trial in Australia, in which they had aimed to achieve a specific level of provitamin A within the fruits produced. They found they had exceeded the target with one line of bananas more than doubling it.

Environmental challenges sometimes regarded as climate change, such as persistent drought, and other conditions (poor soils, prevalent crop diseases and pests) are some of the reasons for genetic modification technology. It is known that four major diseases in bananas causing very serious concerns and losses are (i) *Fusarium* wilt tropical race 4 (TR4), (ii) black Sigatoka, (iii) banana bunchy top disease, and (iv) banana *Xanthomonas* wilt [3]. There are also larger number of diseases and pests of lesser importance, including yellow Sigatoka, freckle, banana bract mosaic, banana streak, Moko, blood disease, nematodes and weevils. These diseases impact on the nutrition and other commercial values or uses of banana fruit including the stem. Conventional breeding methods have limited success in combating these environmental challenges. The purpose of transgenicity includes (i) enhancement of fruit/quality and value-added traits; (ii) pharmaceutical/medicinal purpose; (iii) improvement in productivity and (iv) health and nutrition. Some target traits in transgenic manipulation in banana include drought tolerance, disease resistance, stress and insect resistance, vitamin A content, colour change and vaccine production.

Significant research in genetic engineering has resulted in nutritionally rewarding bananas. It is known that bananas were domesticated over the past 7000 years. The wild banana before GMO, usually contain big, hard seeds and have a little amount of flesh. They have been selectively bred to have tiny, non-fertile seeds. 'Without using selective breeding, bananas would have been almost inedible'. With all the benefits and ethical considerations of biotechnology/genetic engineering, it continues to advance every area of human nutrition. The question has been asked: Are GMO bananas the next 'superfood'; is there a need for a 'super banana'? The 'super banana' is set to start clinical trials in the United States. Scientists hope to start distributing it to African growers by 2020. Also, scientists from the Queensland University of Technology have created bio-fortified bananas having higher levels of vitamin A capable of preventing vitamin A deficiency (VAD) induced blindness and death among the millions of malnourished children. It is known that VAD is one of the most easily cured illnesses, and is treated with a simple vitamin supplement. 'Good science can make a massive difference here by enriching staple crops such as Ugandan bananas with pro-vitamin A and providing poor and subsistence-farming populations with nutritionally rewarding food', said the project leader, Professor James Dale. The other areas of advances in plant biotechnology include 'Transgenic Cavendish bananas with resistance to *Fusarium* wilt tropical race 4'—published in *Nature Communications* [4]; 'Exogenous application of chemicals in combinations (1-methylcyclopropene—1-MCP and salicylic acid) with excellent effect on the postharvest physiology and quality of bananas such as inhibit the respiration rate, ethylene production, decay incidence, soluble sugar, and soluble solids content, delayed softness and colour change'—published 2018 in the *Journal of Food processing and Preservation*. There is still a need for conventional (traditional) banana breeding although most of the funding is now allocated to creation of transgenic bananas. However, many countries are against the use of genetically modified crops.

Banana cultivation is affected by various diseases; the most serious being the bunchy top disease caused by the banana bunchy top virus (BBTV) and *Fusarium* wilt caused by the virulent fungus, *Fusarium oxysporum* f. sp. *cubense* tropical race 4 (TR4). Bananas are difficult to genetically improve and significant research has been going on in plant. Gene-editing has helped create plants that produce higher yields to meet the growing demand along with higher nutritional content [5]. Transgenic Cavendish with resistance to TR4 exists. Several successful attempts have demonstrated the strength of transgenics in developing abiotic stress tolerance and disease resistant transgenic banana varieties. Many other similar investigations are currently ongoing that would lead to better production, nutritious and healthful bananas. Recent transgenic studies on bananas have shown that the following challenges and opportunities for future genetic improvement exist:

a. Control of diseases that are major constraint to banana cultivation and consumption worldwide.

b. Few of the GM bananas have qualified for field studies and some are currently undergoing nutritional human trials.

c. Improving the nutritional value of bananas is a prime target.

d. Increasing banana fruit shelf life.

e. Enhancing bananas as a technologically functional food, for instance, producing banana fruit with increased levels of minerals and vitamins, especially precursors of certain vitamins.

The principal aim of function and processing technologies is to develop safe, technologically functional and nutritious food, especially the staples by the best available and productive technology. The book 'Banana Nutrition—Function and Processing Kinetics', is one covering trend topics on banana plant and fruit. Various processing methods converting this fruit into value-added and healthful products are highlighted. All sections contain recent advances in banana biotechnology that will appeal to farmers, plant breeders, food industry, investors and consumers. Also, the information contained will be beneficial for researchers to further harness this crop in controlling many diseases and especially non-communicable nutrition-related human illnesses. The book therefore contains substantial scientific information written in a form that is easy to understand.

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Chapter 2

Pharmacological Activities of Banana

Bashir Ado Ahmad, Umar Abdullahi Zakariyya,
Mujaheed Abubakar, Musbahu Muhammad Sani
and Musbahu Adam Ahmad

Abstract

Plants have been in use in traditional medicine since antiquity, and many active metabolic products with biological significance are obtained from them. Recently, pharmaceutical industries have developed great interest in utilizing these products as an alternative to the chemically synthesized drugs. This is due to the discovery of important new medicines from the plants, because of studies on how people of different background use plants as cure and treatment for many diseases, and side effects of the synthesized drugs. Banana, an eatable fruit produced by some herbaceous flowering plants of the genus *Musa*, is one of the valuable fruits with proven pharmacological potentials. Bananas are spread almost all over the world. Different chemical constituents like apigenin glycosides, myricetin-3-O-rutinoside, kaempferol-3-O-rutinoside, dopamine, and serotonin have been reported in different parts and varieties of banana. The presence of carbohydrate, proteins as well as flavonoids, makes bananas useful in both nutrition and therapeutics. Pharmacologically, bananas have been shown to possess antiulcer, antimicrobial, and antioxidant activities. This chapter discusses the essential information on banana, including its varieties, distribution, pharmacological actions, and its relevance in pharmaceutical industries. This will be beneficial for researchers to further harness the robustness of this fruit in controlling many diseases and modification of drugs.

Keywords: banana, traditional medicine, phyto-constituents, pharmacological activities, pharmaceutical formulation

1. Introduction

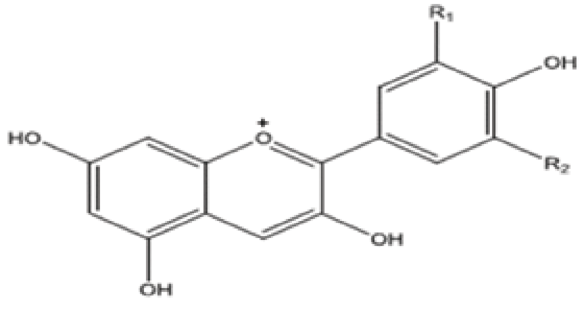
The general term “banana” describes the cultivated varieties of the genus *Musa*, made up of two subgroups, the sweet bananas and plantain [1]. It has different parts, such as fruit, peel, leaves, roots, and pseudostem, which have shown various pharmacological effects [2]. Banana is of great use both traditionally and pharmacologically and this is attributed to the presence of its diverse phyto-constituents as the pulp and peel extracts of banana are shown to have fatty acids, steryl esters, and sterols, besides oleic and linoleic acids [3]. The fruit is also a rich source of valuable phytonutrients, including phenolic compounds and vitamins [4, 5]. The bioactive components produced by plant secondary metabolism, in addition to elements such as phosphorus, and potassium, have obvious therapeutic potential by contributing toward its pharmacological activities [6].

Various parts of ripe and unripe forms of banana plant have been shown to possess prominent anti-diabetic [7], antiulcer [8], and radical scavenging activities. Lately, banana has been utilized as a vector for many vaccines due to increased bioavailability and easy administration [9]. Not only that, pectin extracted from banana is said to be used as pharmaceutical excipient in tablet formulation [10]. This chapter focuses mainly on the pharmacological studies that validate the traditional uses of banana for different types of diseases and highlights the geographical distribution of banana and its uses in pharmaceutical industries.

2. Banana phyto-constituents

Several researches have been carried out to determine the phyto-constituents of various parts of banana. The flower of *Musa paradisiaca* was reported to contain tannins, saponins, reducing and non-reducing sugars, sterols, and triterpenes. In addition, hemiterpenoid glucoside (1,1-dimethylallyl alcohol), syringin, and benzyl alcohol glucoside have been isolated from the flower [11]. The structure of a tetracyclic triterpene isolated from the flowers of *Musa paradisiaca* was established as (24R)-4α-14α, 24-trimethyl-5-cholesta-8, 25 (27)-dien-3β-oil [12]. Banana bracts were also investigated as a potential source of natural colorants. Monomeric anthocyanin content was found to be 32.30 mg/100 g. Other anthocyanins include 3-rutinoside derivatives of delphinidin, pelargonidin, peonidin, and malvidin [13].

Banana pulp contains antioxidants, including, vitamins, carotenoids, and phenolic compounds such as catechin, epicatechin, lignin, tannins, flavonoids as well as anthocyanins [14]. Serotonin, norepinephrine, tryptophan, indole compounds, starch, iron, crystallizable and non-crystallizable sugars, vitamin C, B-vitamins, fats, and mineral salts have been noted in the fruit pulp of *Musa paradisiaca var. sapientum* [15]. Cellulose, hemicelluloses, and amino acids like arginine, aspartic acid, glutamic acid, leucine, valine, phenylalanine, and threonine have been isolated from the pulp and peel of *Musa paradisiaca* [16]. Acyl steryl glycosides like sitoindoside-I, II, III, and IV as well as steryl glycosides such as sitosterol gentiobioside,



General Structure of Anthocyanin

Anthocyanidin	R_1	R_2
Delphinidin	OH	OH
Pelargonidin	H	H
Peonidin	OCH_3	H
Malvidin	OCH_3	OCH_3

Figure 1.
General structure of anthocyanin and some common anthocyanins found in banana [69].

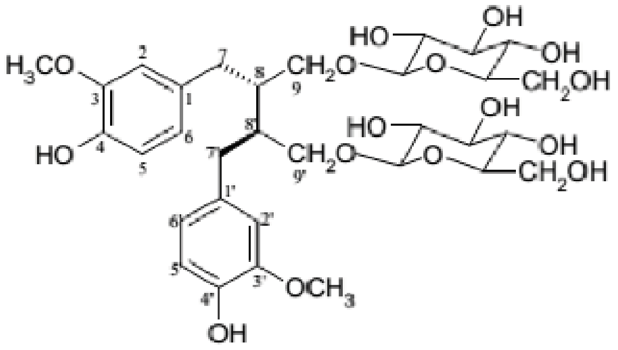


Figure 2.
Structure of lignin [70].

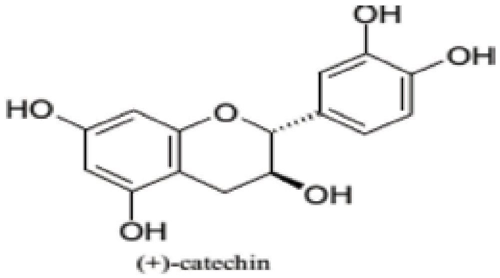


Figure 3.
The class of flavonoid present in banana fruit (Flavan-3-ol) [70].

sitosterol myo-inositol-β-D-glucoside were isolated from the fruit of *Musa paradisiaca* [17]. Banana peel is generally discarded as a waste; however, it is a very rich source of important phyto-constituents. The peel contains 6–9% dry matter of protein and 20–30% fiber. Usually the ripe banana peels contain 30% free sugar and 15% more starch than green banana peels. Moreover, banana peel is a good source of lignin, cellulose, and hemicellulose with variety of active functional groups (carboxyl, hydroxyl, and amine) [18, 19]. Phytochemical analysis of *Musa paradisiaca* and *Musa acuminata* peels revealed the presence of phenols, carbohydrates, terpenoids, and saponins [20]. The presence of such potent phyto-constituents in banana makes it a great target for nutritional and therapeutic researches. The structures of some of the important isolated compounds in banana are shown in **Figures 1**–**3**.

3. Pharmacological activities of banana

Banana has various pharmacological effects. The prominent ones of more relevance to health care are discussed in this section.

3.1 Antioxidant activity

Reactive oxygen species (ROS) are oxygen radicals with unpaired electron involved in both physiological and pathological conditions. Antioxidants, on the other hand, prevent free radical damage by scavenging the radicals. Banana contains various compounds that exert such antioxidant activity [21].

The antioxidant property of banana peel extracts *(Musa paradisiaca L.)* was explored using a group of rats exposed to a normal diet and compared to another group fed with fatty acid-rich diet. Oxidation markers like malondialdehyde (MDA) were measured. It was observed that subjects treated with banana peel extract displayed a significant decrease in concentrations of the peroxidation products (MDA), peroxides, as well as conjugated dienes. Meanwhile, antioxidant enzymes, catalase, and superoxide dismutase activities were raised significantly in the treated subjects. The level of an important antioxidant, reduced glutathione (GSH), also increased [22]. In another research conducted by [23], powdered candi banana (*Musa paradisiaca*) was extracted using ethanol and ethyl acetate in an ultrasonic bath. The results indicated that the antioxidant activity (IC_{50}–50% inhibitory concentration) of ethanol extract and ethyl acetate was 3374.13 ± 123.46 and 40318.19 ± 1014.90 ppm, respectively, hence, leading to the conclusion that the antioxidant activity of ethanol extract is higher than that of ethyl acetate.

An *in vitro* antioxidant study of *Musa sapientum, Musa paradisiaca, Musa cavendish,* and *Musa acuminata* peels was conducted using 2,2-diphenyl-1-picrylhydrazyl radical (DPPH), hydrogen peroxide (H_2O_2) radical scavenging assay, and ferric reducing power assay. The results showed that *Musa acuminata* has the highest antioxidant activity followed by *Musa cavendish* against DPPH radical. In ferric reducing power and H_2O_2 scavenging assay, *Musa acuminata* also showed best antioxidant activity when compared with other extracts. The study revealed that the peels of *Musa* species possess significant *in vitro* antioxidant activity, hence, the conclusion that eating the peel of banana fruit would be beneficial considering its potential antioxidant property [24]. It was also reported that ethanol extracts of unripe Cavendish (*Musa acuminata L)* and Dream banana *(Musa acuminata colla. AAA cv* Berangan) peels have excellent radical scavenging activities with an IC_{50} of 90.28 μg/mL (for Cavendish) and 113.09 μg/mL (for Dream banana). The researchers ascribed this effect to the abundant phenols, flavonoids, and tannins detected in the peel extracts [25]. It can therefore be inferred that the antioxidant compounds like phenols and flavonoids present in the peel are involved in DPPH radical inhibition.

In another study that investigated the antioxidant activity of banana flowers of six distinct Malaysian cultivars, namely *Musa balbisiana* cultivars pisang Abu (P. Abu) and pisang Nipah (P. Nipah); *Musa acuminata* cultivars pisang Berangan (P. Berangan), pisang Susu (P. Susu), and pisang Mas (*P. Mas*); and *Musa paradisiaca* cultivar pisang Rastali (P. Rastali), it was found that, of all the six cultivars, P. Susu possess the highest phenolic content (80.13 ± 4.64 mg of GAE/g of extract) and the highest 2,2′-azido-bis (3-ethylbenzothiazoline-6-sulphonic acid) $ABTS^+$ and DPPH free radical scavenging activities. This is indicative of a strong relationship between the phenolic contents and radical scavenging power of the flowers [26]. The study of antioxidant activity of banana parts, namely tepal (methanol, ethanol, and aqueous extracts), peel, and pulp (methanol extracts) as well as pure syringin was carried out using DPPH radical scavenging assay and the result showed excellent antioxidant activity in tepal methanol extract, moderate activity in both tepal and peel ethanol and aqueous extracts. Meanwhile, mild activity was observed in pure syringin and pulp extracts. The DPPH radical scavenging activity of the different successive extracts of *Musa paradisiaca* showed direct proportion with sample concentration and the researchers attributed this role to the abundant phenols and flavonoids present in the extracts (**Figure 4**) [27]**.** DPPH and ferric ion reducing antioxidant power (FRAP) assay methods were employed to determine the radical scavenging ability of banana fruit extracts. The extract prepared from ethanol had higher antioxidant activity, while solvent hexane fraction showed moderate scavenging activity. Moreover, banana peels extracted with ethanol demonstrated potent antioxidant activity on DPPH, with an IC_{50} of 19.10 μg/mL. In the same vein, the ethanol extract of the peels exhibited significant antioxidant activity

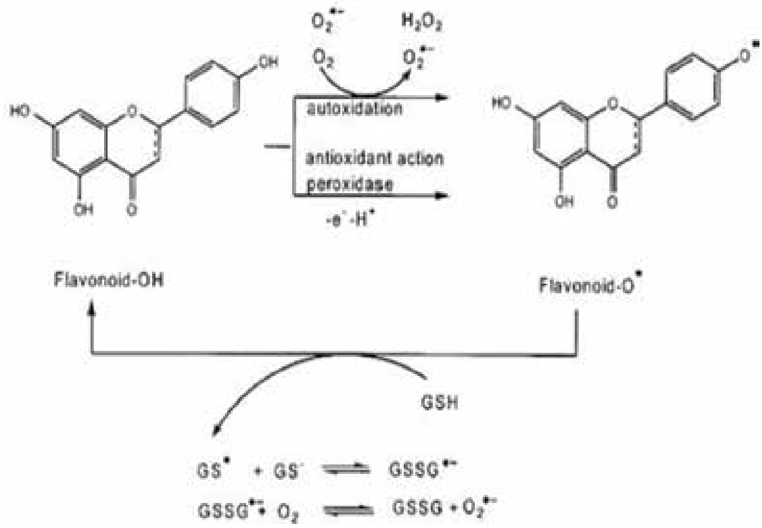


Figure 4.
Antioxidant mechanism of flavonoids detected in banana. Enzymatic and/or chemical auto-oxidation of the flavonoids generates the flavonoid semiquinone radical, which may be scavenged by reduced glutathione (GSH), thereby generating the flavonoid and generating thiyl radical of glutathione. This thiyl radical may react with GSH to generate a disulfide radical anion which rapidly reduces molecular oxygen superoxide anion radical, which can be further detoxified by superoxide dismutase enzyme [71].

on FRAP with IC_{50} values of 55.10 μg/mL. The pulp extracted with ethanol showed excellent FRAP radical scavenging activity with IC_{50} of 46.40 μM of Fe^{2+}/mg [28]. A comparative study of antioxidant effects of banana and papaya peels was carried out using DPPD and ferric reducing activity methods. The outcome showed clearly that banana peel extract scavenges more free radicals than that of papaya [29].

3.2 Anticancer effect

Cancer is currently among the major world health concerns. It is characterized by abnormal cell growth. Natural products like banana are being utilized to combat the deadly disease. Banana is found to possess anticancer (colorectal) property by an *in vitro* assay of hill banana (Virupakshi). The fruit juice inhibits human colorectal adenocarcinoma cell line (HT-29) and causes mortality at a very low concentration [30]. It was hypothesized that CellQuest, a patented formula comprising high level of tannic acid (TA) extracted from *Musa paradisiaca* (plantain), suppressed the tumor cell proteasome activity. This study suggested that CellQuest aims at the proteasome selectively in tumor cells, which possibly contributes to the anticancer effect [31]. Anticarcinogenic substances present in banana peels like saponins can combat abnormal cells (**Figure 5**). The degree of anticancer effect corresponds to the degree of ripeness of the fruit. A research was conducted by a Tokyo university professor in which numerous health advantages of diverse fruits such as banana, grape, water melon, apple, pineapple, persimmon as well as pear were related. The result showed that banana displayed better augmentation of leucocytes, improvement of body immunity, and production of anticancer substance [32].

3.2.1 Cytotoxic effects

Banana extracts were tested for their ability to suppress the growth of breast cancer cell line (MCF-7) and human colorectal carcinoma (HCT-116) tumor cell lines along with the human umbilical vein endothelial cells (HUVEC cell).

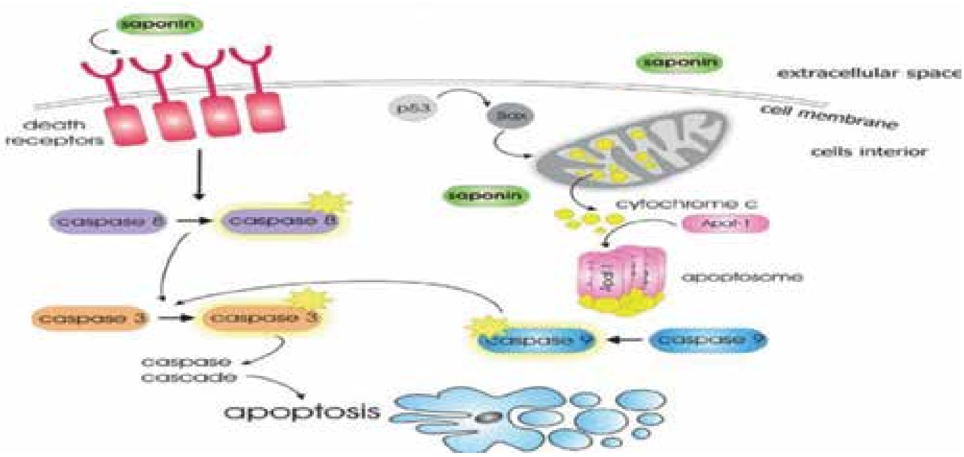


Figure 5.
Mechanism of pro-apoptotic effect of saponins, compounds present in banana [72].

The extracts showing more than 60% inhibition of cell proliferation were the active extracts. Among these, hexane extract of banana peel and pulp showed maximum toxicity against HCT-116 and MCF-7 cell lines with percentages of 62.04 and 61.21%, respectively, while the aqueous and ethanol extracts indicated low anti-proliferative activity against HCT-116 and MCF-7. Interestingly, all the tested extracts showed virtually no cytotoxic effect against the normal cell lines [28].

3.2.2 Anti-angiogenic activity

In a research that assessed the anti-angiogenic potential of different banana extracts, rat aorta ring assay was employed using suramin as a reference drug. Banana extracts exhibiting over 60% inhibition of sprouting of blood vessels were considered active extracts. Two extracts exhibited potent inhibitory activity (>60%) with maximum inhibition of 85.32% produced by the hexane extract of banana peel. These significant inhibition values were very much similar with the standard drug (suramin), which showed potent inhibition of microvessel growth [28].

3.3 Antiulcer activity

Ulcer has been a major challenge of developing nations. It is a lesion caused by factors including the bacteria *Helicobacter pylori* and excess acidity. Researchers tested the potency of banana against this complication and it was shown to have significant antiulcer activity by [33] who evaluated the ulcer index, gastric wall mucus, gastric juice pH, and volume of ulcer-induced animals. The results showed the preventive effect of tepal and peel extracts against indomethacin plus pylorus ligation-induced ulcer by 68.80 ± 20.53 and 43.22 ± 14.82%, respectively. In addition, reduced gastric juice volume and increased gastric wall mucus were observed in both the tepal and peel extract-treated groups. Finally, the study revealed that banana tepal and peel extracts were able to prevent the induced ulcer by strengthening the gastric mucosa and decreasing the acidity of the gastric juice. In another study on the antiulcer effects of chloroform and ethanol extracts of banana, in ulcer-induced rats by ethanol, it was found that, both the chloroform (200 mg/kg) and ethanol extracts (400 mg/kg) were effective against the induced ulcer by significantly ($p < 0.05$) reducing the number of ulcer and ulcer index as compared to the standard ulcer drug, ranitidine [34].

Leucocyanidin showed protective effect against ulcer induced by aspirin. The compound was extracted from *Musa paradisiaca* (plantain) by solvent fractionation and was described as the active antiulcer compound [35]. Dried plantain pulp powder is a potent herbal drug for the treatment of peptic ulcer disease as suggested in a research conducted by [8], in which the ulcer protective and curing activities of unripe plantain were explored.

3.4 Antidiabetic effect

Diabetes, which can be insulin dependent or non-insulin dependent, poses a great threat to humanity. High level of glucose is prominent in diabetic patients and attempts have been made to counteract that using several plants including banana. Investigation into the anti-hyperglycemic effect of ethanol extract of *Musa sapientum* (*EMS*), *M. paradisiaca (EMP), Musa cavendish (EMC),* and *M. acuminata (*EMA) peels by oral glucose tolerance test in glucose-loaded (2 g/kg p.o) normoglycemic (having normal concentration of glucose) rats was done by [24]. It was observed from this study that animals treated with EMC (500 and 1000 mg/kg, p.o) and EMA (200 and 400 mg/kg p.o) showed marked anti-hyperglycemic effect ($p < 0.01$). Also, both EMS (200 mg/kg, p.o) and EMP (500 mg/kg, p.o) depicted significant ($p < 0.01$) decrease in blood glucose level. Another study aimed at evaluating the *in vitro* antidiabetic activity of methanol extracts of three kinds of fruit peels (lemon, pomegranate, and banana) showed that banana peel exhibited maximum alpha amylase inhibitory activity (80.87% at 1000 μg/mL). Hence, banana peel is more potent among the three, having the highest hypoglycemic effect. Thus, it can be utilized as antidiabetic supplement as compared to the others [36]. The hypoglycemic effect of methanolic extract of mature green fruits of *M. paradisiaca* in normal (normoglycemic) and streptozotocin-induced diabetic (hyperglycemic) mice was evaluated. The results of this experiment indicated that the extract possesses hypoglycemic activity, and hence corroborate folkloric use of the plant in the management of type-2 diabetes mellitus [37]. The effect of *M. sapientum* Linn. sucker administration on pancreas histology, fasting blood glucose as well as body weight in experimental animals made hyperglycemic by alloxan induction were reported by [38]. The sample was found to effectively reduce the glucose level, improve the animal's body weight, and regenerate the damaged pancreas in the induced rats. Hence, banana is perhaps the best candidate for diabetic control.

3.5 Antimicrobial activity

The antimicrobial properties of ethanol and acetone extracts of banana peels were evaluated by well diffusion assay against different microbial strains. An 80% acetone extract inhibited bacterial species at 600 ppm against Gram-positive bacteria including *Bacillus subtilis* (20.60%), *Staphylococcus aureus* (19.75 mm), *Escherichia coli* (18.15 mm), and *Pseudomonas aeruginosa* (19.57 mm). The presence of phytochemicals including phenolic compounds and tannins is believed to be associated with this antimicrobial property [39]. The Kirby-Bauer sensitivity method was employed to evaluate the antibacterial activity of silver (Ag) nanoparticles synthesized from the stem waste of banana plant. The Ag nanoparticles showed remarkable activity against *E. coli* and *Staphylococcus epidermidis*, with *E. coli* (Gram negative) being more susceptible with an inhibition zone of 12 mm. The research showed that banana stem waste can generate Ag nanoparticles with antibacterial activity against Gram-negative bacteria, *E. coli,* and *S. epidermidis* [40]. In a separate work, fresh green and yellow banana peel of (*Musa*, cv. *cavendish*) fruits treated with 70% acetone were sequentially partitioned with chloroform ($CHCl_3$) and ethyl acetate

(EtOAc). The antimicrobial activities of the extracts and isolated components were evaluated using paper disc method and minimum inhibition concentration (MIC). The EtOAc and water-soluble fractions of green peel displayed high antimicrobial activity [41]. Moreover, the extracts of dried *M. paradisiaca* peel, powder and ash, possessed a good antifungal effect when tested against *Aspergillus niger* [20].

3.6 Wound healing attribute

Banana peel was reported to have wound healing activity through its predominant effects on mucosal defensive factor that enhances DNA synthesis and promotes mucosal cell proliferation. The wound healing activity of both methanol and aqueous extracts of plantain banana (*M. sapientum* var. *paradisiaca*) was assayed in rats. Both extracts were found to increase hydroxyproline, hexuronic acid, hexosamine, superoxide dismutase levels as well the wound tensile strength. The extracts also decreased the wound and scar areas, and lipid peroxidation. These effects were attributed to the antioxidant property of the plantain [42].

3.7 Effect on atherosclerosis

Atherosclerosis is a disease characterized by accumulation of plaque inside the arteries. In a study, Ambon *(Musa paradisiaca)* peel was used to ascertain its effectiveness as anti-atherosclerotic agent by the inhibition of NF-κB (nuclear factor kappa beta) and increasing e-NOS (endothelial nitric oxide synthase) expression in atherogenic rats using immunohistochemical method. It was observed that the extract significantly decreases NF-κβ activity and increased e-NOS activity in a dose-dependent manner. Linear regression showed that the extract can lower NF-κβ activity by 82.1% and increase e-NOS expression by about 95.2%. Therefore, the extract of Ambon banana peel was proven to be effective in preventing

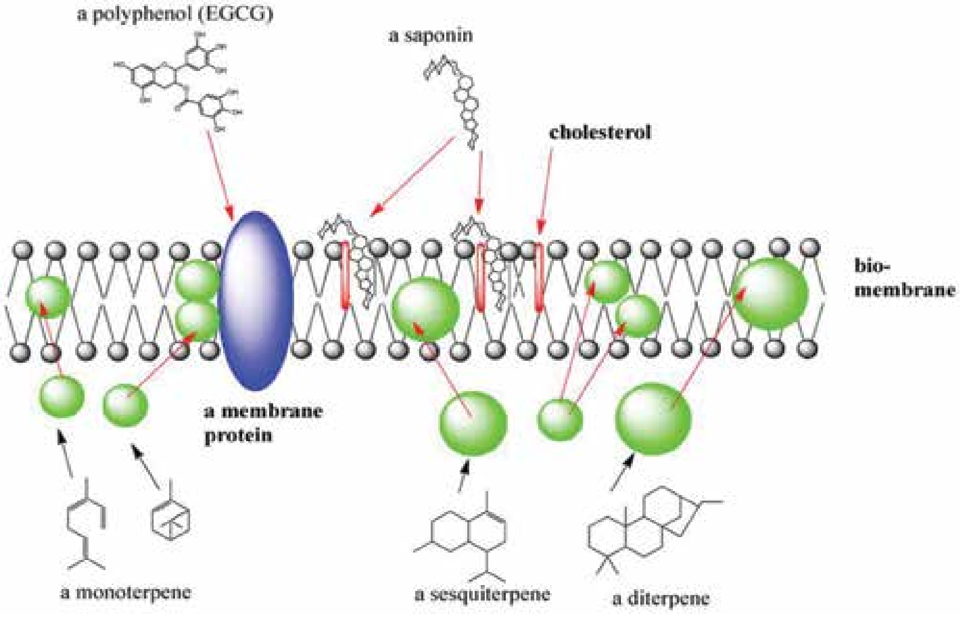


Figure 6.
The cholesterol-lowering activity of banana may be because of the phyto-constituents on cellular membranes. For example, saponins can form complex with membrane cholesterol; polyphenols influence 3D structure of membrane proteins like receptors, transporters, and ion channels); small lipophilic terpenoids assemble in the inner lipophilic core of the biological membrane [73].

atherosclerosis. This finding revealed the effectiveness of the peel extract in inhibiting the atherosclerotic process via suppressing the expression of chemo-attractant molecules and monocyte adhesion and thus the peel extract may be considered a novel therapeutic agent in preventing atherosclerosis [43]. A related study was conducted by [44], in which the effect of saponin, tannin, and flavonoid present in Kepok banana peel against total cholesterol level in obese male mice was measured. The researchers divided 20 obese male mice (*Mus musculus L.)* into four groups and treated them for 14 days. Total cholesterol level of each group was measured using spectrophotometer. It was observed that the Kepok banana peel lowered the total cholesterol level in the tested animals, with more effect in a group administered 8.4 mg/day of the peel extract than in the group administered 16.8 mg/day. It was thus concluded that banana peel extract is effective in lowering the total cholesterol level of obese mice reflecting its anti-atherosclerotic effect (**Figure 6**). The researchers obtained 8.4 and 16.8 mg/day based on the conversion of the effective doses of banana peel extract for rats. By this, 200 mg/kg body weight of banana peel extract can reduce total cholesterol level of rats.

4. Banana and pharmaceutical industries

Pharmaceutical industries demand for fast dissolving tablets [45] to facilitate drug onset of action, higher patient acceptance, and increased bioavailability [46, 47]. Banana, a natural superdisintegrant can be used as pharmaceutical excipient for oral drug delivery due to exhibition of faster drug dissolution which leads to improved bioavailability, effective therapy (therapeutic ratio), improved patient compliance, and satisfies all the standards of fast dissolving tablet. Various formulations were prepared by direct compression method using superdisintegrants like banana (2%), sodium starch glycolate (4%), and cross carmlose sodium (6%). The mixture was analyzed for different pre-compression parameters (angle of repose and tapped density) and post-compression parameters (thickness, drug constituents, weight variation, hardness, wetting time, friability, dissolution and disintegration time as well as drug release). It was concluded from the result that banana powder showed better disintegrating property over synthetic superdisintegrants such as SSG (sodium starch glycolate) and CCS (cross carmelose sodium) [45].

In another work by [48], dehydrated banana powder and potato starch were prepared and subjected to analysis. Physicochemical parameters, bulk and tape densities along with angle of repose, Hausner ratio, Carr's index, solubility, and melting point were assessed. FTIR spectroscopy was then performed to study the interaction between aceclofenac (a non-steroidal anti-inflammatory drug) and the excipients. Direct compression method was employed for the tablet preparation using the disintegrants, and the disintegration time of the tablet formulations was monitored. To depict the release mechanism from the tablet system dissolution, study was carried out and data were fitted to different kinetic models. The result revealed that tablets of banana powder *(M. acuminata)* and potato starch disintegrate more rapidly than that of microcrystalline cellulose. The prepared formulations passed the evaluation tests including weight variation, hardness, friability, and content uniformity. Therefore, banana powder and potato starch have better disintegrant property than the microcrystalline cellulose.

Fermentation is one of the processes used by pharmaceutical industries in drug manufacturing. Effect of banana fermentation product, obtained by subjecting banana pulp juice to a pre-fermentation in the presence of *Streptococcus thermophilus* (DSMZ 28121 strain) and yeast *(Saccharomyces cerevisiae* ATCC 4126T), and post-fermentation conducted in the presence of *Acetobacter* (*Acetobacter aceti,* DSMZ

3508), on antioxidation, probiotics, and pathogenic bacteria was compared to the unfermented banana pulp juice. The fermentation product was found to be effective in antioxidation (having higher superoxide dismutase (SOD) activity when compared to the commercial enzyme product) (**Figure 7**), increasing the number of probiotics (*Lactobacillus acidophilus*), by 4–8 fold (**Figure 8**), in the intestinal tract, reducing the number of pathogenic bacteria (*E coli*), by 4 fold (**Figure 9**), in the intestinal tract, and relieving constipation symptoms. Therefore, the product can be used as an edible or a pharmaceutical composite [49].

Nanoparticles are used to increase the surface-to-volume ratio of pharmaceutical agents. These particles can pass through biological barriers and are made from a wide array of biocompatible materials that can be used in food and pharmaceutical industries [50, 51]. Nanoparticles from native and acetylated banana starch were prepared and used as nanovehicles for curcumin encapsulation and release. Acetylation proved to be a powerful chemical alteration for encapsulation of hydrogen bond donor molecules like curcumin. A strong nanoparticle-curcumin interaction is formed due to increased number of hydrogen bond-accepting sites. This allows more curcumin molecules into the starch nanoparticles. Encapsulation does not affect properties such as particle size and polydispersity index, proving that it is possible to design nanoparticles from banana starch with sizes below 250 nm. This result showed that ABSNp (acetylated banana starch nanoparticle) allowed more controlled release of curcumin in gastric medium, which could be a defining factor in their potential use in drug and nutraceuticals delivery [52].

Banana peel is an abundant byproduct of agro waste which is under investigation as an economical and feasible alternative carbon source for the cultivation and the growth of probiotic *lactobacilli*. It was found that there was no significant difference in the growth of *lactobacilli* between banana peel medium and commercial De Man, Rogosa, and Sharpe (MRS) medium. Banana peel waste can therefore be used for probiotic, *lactobacilli* production. The tested strains of *lactobacillus* demonstrated extraordinary growth at 37°C and pH 6.0. It can be summed up from this work that using banana peel agro waste would be optimal both economically as well as environmentally for probiotics production [53]. It was observed that pectin extracted from banana exhibited a good flow property and can be used as pharmaceutical excipient to prepare the solid and semisolid dosage form [54]. Citric acid is extensively used in dairy, food, beverage, pharmaceutical, and biochemical industries. Current economic pressure and escalating cost of substrates for microbial growth and production necessitate the exploration of alternative organic substrates for microbial production by pharmaceutical industries. Banana peel can be utilized as a substrate for citric acid production by *Aspergillus niger* [55].

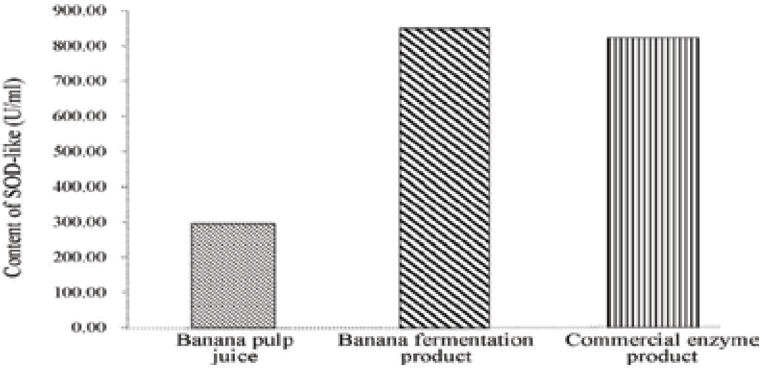


Figure 7.
Measurement of the content of SOD-like in the banana fermentation product [49].

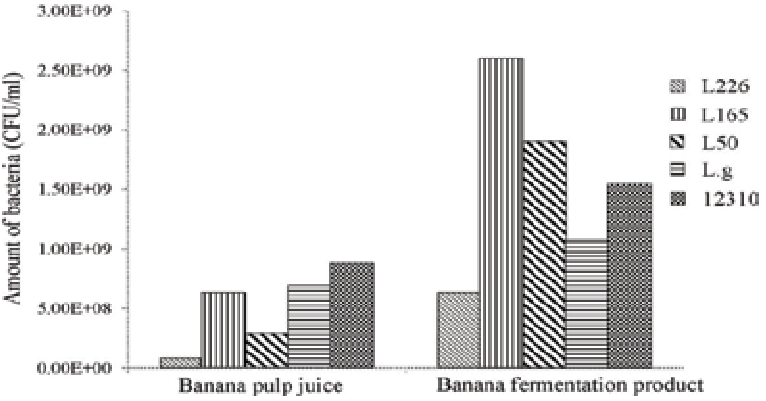


Figure 8.
Effect of banana fermentation product on increasing the number of probiotics [49]. L226 strain = Lactobacillus acidophilus, L165 strain = Lactobacillus rhamnosus, L50 strain = Lactobacillus plantarum, L.g strain = Lactobacillus gasseri, 12,310 strain = Lactobacillus brevis.

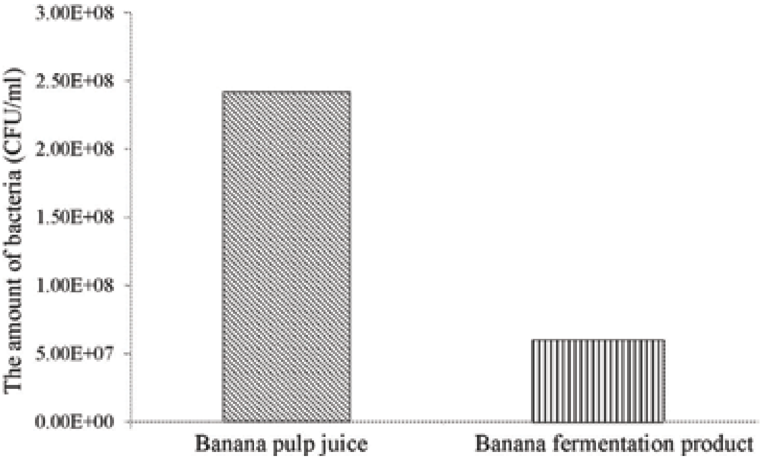


Figure 9.
Action of banana fermentation product on the number of pathogenic bacteria in the intestinal tract [49].

The shoot and callus cultures of banana (*Musa* sp.) were used to assess the accumulation of L-DOPA (L-3,4-dihydroxyphenylalanine), an important intermediate of plant secondary metabolism which is orally administered to relieve Parkinson's disease (a progressive disorder associated with a deficiency of dopamine in the brain). Treatment of the cultures with L-tyrosine and L-phenylalanine yielded higher levels of L-DOPA as compared to those in control cultures. Among the two amino acids, phenylalanine induced higher accumulation of L-DOPA. The study thus indicates that banana may be a potential resource to produce L-DOPA [56].

5. Banana in global traditional medicine and beliefs including geographical spread

5.1 Banana in global traditional medicine and beliefs

Parts of banana, which include roots, pseudostems, stems, leaves, and flowers, have long been utilized in local and traditional medicine in America, Asia, Oceania, India, and Africa [57]. Based on the resources of Iranian traditional medicine, bananas are prescribed for depressed patients [58]. Iranian traditional medicine as a complementary and alternative medicine involves several non-pharmacological treatments, among which food therapy is the most notable. Data from an Arabic source indicate that *Musa* species is useful against heat in the chest, lungs, and the bladder, and softens the stomach [59]. Report by [60] confirmed that banana fruit from India have been used traditionally to fight off a large number of sicknesses. This attribute is due to the presence of various constituents present in the fruit. For example, the anti-depressive role, blood pressure control, and anti-anemic property may be due to the presence of banana's tryptophan, high potassium, and high iron contents, respectively. Banana also helps during body's recovery from nicotine withdrawal thereby helping people to quit smoking perhaps because banana is rich in not only potassium and sodium but also vitamins B6 and B12. The ability of banana to revamp normal bowel action, attributed to its high fiber content, made it a good candidate for treating constipation. It is also used in heartburns and ulcers due to natural antacid effects as well as in stress conditions ascribed to the presence of potassium. Topical application of banana peel has long been used in treating burn wounds in Brazilian local and traditional medicine [61]. Wounds were wrapped around with cataplasm prepared using peels of ripe bananas which can serve as an analgesic and also reduce swelling. In case of urgency, banana peel can be wrapped directly around an injury due to its antiseptic nature [62].

Banana peel contains anti-histamines, which works by subduing and blocking histamines such that the effect of the histamines is undone. Histamines are the chemical compounds released in body cells that cause allergic reactions. Hence, it is applied on bug bites, where anti-histamines in the banana peel sink into the skin and prevent further swelling and cure itching [63].

5.2 Banana geographical spread

Worldwide distribution of some banana cultivars according to their genomic group is summarized in **Table 1** below.

Genomic group	Cultivar	Fruit usage	Geographical distribution
AA	Frayssinette, Figue sucrée	Dessert banana	All continents
	Ouro	Dessert banana	Brazil
AAA	Gros Michel, Lacatan Poyo	Dessert banana	All continents
	Intuntu	Cooking	East African highland
	Caipira	Dessert banana	Brazil
	Yangambi-5	Dessert banana	Central and West Africa
	Grand Nain, Valery	Dessert banana	Egypt
	Mujuba	Cooking	East African highland
AAAA	Champa Nasik	Dessert banana	East African highland
AAAB	Goldfinger	Dessert banana	America and Australia
AB	Safet Velchi	Dessert banana	India and East Africa
	Sukari	Dessert banana	India and East Africa
AAB	Maca, Silk	Dessert banana	All continents
	Prata, Branca, Pacovan	Dessert banana	Brazil, India and Egypt
	French, Horn	Cooking	Africa Caribbean
	Corne	Cooking	Africa Caribbean
	Batard, Mbouroukou-1, Mbouroukou-3	Cooking	Belgium
	Terra, Pacovan, D'Angola	Dessert banana	Brazil

Genomic group	Cultivar	Fruit usage	Geographical distribution
ABB	Figo Vermelho or Figo Cinza Bluggoe Fougamou	Dessert banana Cooking Dessert banana	Brazil Philippines and America Philippines and America
AABB	Ouro da Mata	Dessert banana	Brazil
ABBB	Klue Terapod	Cooking	Philippines and America
BBB	Saba	Cooking	Indonesia and Malaysia

Note: Represents combinations of the Musa balbisiana Colla and M. acuminata Colla genomes. Cooking means plantain varieties.
Source: [64–68].

Table 1.
Banana geographical distribution showing genomic group, cultivar, and type.

6. Conclusion

Bananas are widely used all over the world as food staples and for medicinal purposes. This is for their interesting bioactive secondary metabolites. Phytochemical and pharmacological studies of bananas and plantain are expanding as it has been demonstrated that *Musa* species extracts possess numerous pharmacological activities, which are ascribed to their phyto-constituents like phenols, carotenoid, and amines. There is a growing interest in developing a banana-based phytomedicine for wound healing and treating Parkinson's disease, considering the ethnopharmacological data available on the potentials of banana fruit. To achieve that, issues such as modality, quality control, efficacy, safety, and toxicity need to be addressed at both preclinical and clinical levels. Finally, looking at the genetic diversity of banana species and its adaptation to different environmental conditions, ethnopharmacological investigations will provide the suitable support needed for clinical usage of secondary metabolites of banana species in modern medicine. Furthermore, thorough phytochemical screening needs to be undertaken to ascertain the active components in different types of extracts of banana parts. This will enrich the literature and provide a solid base for scientific arguments as against the current reliance on empirical and anecdotal assumptions.

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Conflict of interest

No conflict of interest.

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Chapter 3

Banana Bioactives: Absorption, Utilisation and Health Benefits

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Abstract

Banana is an important fruit consumed globally and cultivated in humid and subtropical climes. The fruit comprises nutrients in its pulp and peel with beneficial properties. Banana in its unripe form, consists of indigestible compounds, resistant starch and dietary fibres. The starchy fruit degrades to fructose and sucrose when ripe, thus reducing its starch content. Aside its carbohydrate profile, essential macro and micro minerals, vitamins and phenolic compounds are other nutrients present in pulp and peel of the fruit. Resistant starch, an indigestible compound available in banana fruit, escapes absorption in the small intestine and is transported to the large intestine where digestion takes place. This occurrence makes banana a preferred fruit for consumers suffering from diabetes. Polyphenols, present in minute concentration in the fruit, functions as antioxidants, thus contributing immensely to the prevention of metabolic degenerative diseases. This chapter further examines available nutrients present in banana fruit, their absorption and utilisation in the body. The chapter also brings to the fore, the health benefits of consumption of ripe, unripe and processed banana products.

Keywords: banana, bioactives, nutrigenomics, antioxidants, banana utilisation

1. Introduction

1.1 Overview on banana

Banana is one of the world's most important fruit consumed globally. The fruit (**Figure 1**) grows well in a scale of about 1000 m altitude and sometimes even in the subtropics with higher altitudes. Its name *Musa* is derived from the word "*Mouz*" which is an Arabic name. The name was given to banana plant to honour a Roman physician named *Antonia Musa* who lived in the first century [1]. Sadia and Azizuddin [1] reported that *Musa* belongs to the family *Musaceae* and is divided into four edible cultivars namely: *Rhodochlamys, Eumusa, Callimusa* and *Australimusa*. There are presently diploid, triploid or tetraploid genome groups with the main genome groups represented as AA, AB, AAA, AAB and ABB [1]. Plantain, a cultivated banana variety and often referred to as the cooking-type banana is obtained from *Musa acuminata* (genome "A") and *Musa balbisiana* (genome "B") species [2]. Plantain belongs to the AAB genome, while the commercial export market Cavendish subgroup consists of the AAA genome [1]. Cooking and dessert banana contain substantial amount of nutrients thus qualifying the fruit to be the world's

Figure 1.
The diversity of banana and plantains with various genome compositions [2].

fourth leading agricultural crop [3]. Banana is said to be among human foods which was introduced in the first century. The fruit is cultivated in more than 130 countries throughout tropical and subtropical regions with over a harvested area of approximately 10 million hectares [4]. Furthermore, countries in Latin America such as Ecuador and Columbia have been reported to be major producers of the fruit, while the United States and European Union import the highest amounts of banana [4].

Plantains when compared with unripe dessert bananas differ in terms of plantains being larger in size, possessing more finger body mass and also having higher starch content [5]. Plantains are economically important and serve as a major staple food [6] in some countries such as India and other countries of Latin America and African origin [3]. Plantains are considered as a very important source of energy and starch [7] and are described as sweet acid starchy bananas majorly consumed upon frying or boiling [3]. Similarly, dessert banana serves as a source of energy for athletes due to its potential benefits for sports application [1]. Hence, in some countries, the fruit is used in the production of a variety of energy drinks as well as dried banana bars for athletes. In addition, the fruit also prevents athletes from muscular contractions as it contains significant amount of vitamins and minerals [8]. The works of Doymaz [9] and Pareek [10] showed that banana and plantain contains low amount of protein and substantial amounts of carbohydrates (hemicellulose, starch and pectin), vitamins A and C, potassium, calcium, sodium and magnesium. Dessert and cooking banana plant parts: roots, leaves, flowers, stem and pseudostems have long being used in traditional and indigenous medicine due to their therapeutic properties in various countries of the world such as Africa, America, Asia and Oceania [11]. These beneficial plant parts have been employed in the treatment of various ailments such as snakebite, inflammation, intestinal colitis, dysentery and diarrhoea [8]. Presently, several authors have investigated the potential of banana in mitigating type I and II diabetes mellitus [9, 12], its role in the inhibition of carbohydrate-digesting enzymes (α-glucosidase and α-amylase), glucose absorption [13] and its antioxidant activity [14]. Compared with plantain, most available reports are on changes in chemical composition of dessert banana cultivars during ripening [5, 15–17]. Plantains are rich in nutrients and their biochemical composition varies with growth stage and maturity [5]. Overall, pulp and peel of both cooking and dessert banana can serve as natural sources of amine compounds, antioxidants, carotenoids and polyphenols [11].

Production of banana can be limited by biotic and abiotic stress factors. Thus, improving the nutritional quality, ability of the fruit to adapt to different geographical conditions and production of new disease resistant varieties using genetic engineering are very important [18]. The science behind genetic modification of bananas therefore aims at increasing productivity and nutritional value and this could be one of the sustainable strategies to address food insecurity in the near future [19].

2. Nutritional composition of banana fruit

Banana and plantain consist of a high nutritional value (**Table 1**) which contributes to an improved absorption of numerous nutrients with minimal fat absorption [18]. Bananas are effective in maintaining plasma glucose and possibly improving endurance exercise performance [20]. Banana fruit is a rich source of phytochemicals, including unsaturated fatty acids and sterols. In the works of Wall [21], composition of ‘Dwarf Brazil’ banana was reported to be 12.7 mg/100 g vitamin C, 12.4 mg/100 g retinol activity equivalent (RAE) vitamin A, 17.9% total soluble solids (TSS) and a moisture content of 68.5%. Wall [21] further reported concentrations of 4.5 mg/100 g vitamin C, 8.2 mg RAE/100 g vitamin A, 20.5% TSS and moisture content of 73.8% for ‘Williams’ banana cultivar with the author also showing that cultivars of banana have different nutrient concentrations. An average-sized banana was found to contain 450–467 mg of potassium (K) [22]. Banana is rich in fibre with a medium-sized banana containing about 6 g of fibre. Dessert and cooking banana have been implicated to contain vitamin B, C, macro and micro essential minerals, α- and β-carotene as well as higher concentrations of lutein than provitamin A pigments [20] and all in varying concentrations. As stated in the works of Pareek [10], it was reported in Hawaii that ‘Apple’ bananas

Genome	Cultivars
AA	‘Inarbinal’, ‘Paka’, ‘Matti’, ‘Anakomban’, ‘Pisang Jari Buaya’, ‘Pisang Lilin’, ‘Senorita’, ‘Kadali’, ‘Sucrier’ (‘KulaiKhai’, ‘Lady’s Finger’, ‘Orito’, ‘Pisang Mas’)
AAA	‘Ambon’, ‘Cavendish’ (‘Dwarf Cavendish’, ‘Giant Cavendish’, ‘Grand Naine’, ‘Williams’), ‘Gros Michel’ (‘Cocos’, ‘Highgate’, ‘Lowgate’), ‘Ibola’, ‘Basrai’, ‘Lujugira-Mutika’ (‘Beer’, ‘Musakala’, ‘Nakabulu’, ‘Nakitembe’, ‘Nfunka’), ‘Pisang MasakHijau’ (‘Lacatan’), ‘Red’ (‘Green Red’), ‘Robusta’ (‘Harichal’, ‘Malbhog’)
AAAA	‘Pisang Ustrali’
BB	‘Bhimkol’, ‘Biguihan’, ‘Gubao’, ‘Pa-a-Dalaga’, ‘Tani’
BBB	‘Abuhon’, ‘Inabaniko’, ‘Lap Chang Kut’, ‘Mundo’, ‘Saba Sa Hapon’, ‘Saba’, ‘SabangPoti’, ‘Turrangkog’
AB	‘Kunnan’ (‘Adukkan’, ‘Poonkalli’, ‘PoovillaChundan’), ‘Ney Poovan’ (‘Kisubi’, ‘Safed Velchi’), ‘SukaliNdizi’ (‘Kumarangasenge’)
AAB	‘False Horn’ (‘French’, ‘French Horn’), ‘Laknau’, ‘Maia Maoli’, ‘Moongil’, ‘Mysore’ (‘Sugandhi’), ‘Nendran’, ‘Pisang Raja’, ‘Plantain Horn’, ‘Pome’ (‘Pachanadan’, ‘Pacovan’, ‘Prata Ana’, ‘Virupakshi’), ‘Popoulu’, ‘Ilohena’, ‘Rasthali’, ‘Silk’
ABB	‘Bluggoe’ (‘NallaBontha’, ‘Pisang Batu’, ‘Punda’), ‘Pisang Awak’ (‘KlueNamwa’, ‘Karpuravalli’, ‘PeyKunnan’, ‘Yawa’), ‘Monthan’, ‘Peyan’, ‘KlueTeparot’, ‘Pelipita’, ‘Kalapua’, ‘Cardaba’
AAAB	‘Atan’
AABB	‘Kalamagol’, ‘Laknau Der’,
ABBB	‘Bhat Manohar’
AS	‘Aso’, ‘Kokor’, ‘Ungota’, ‘Vunamami’
AT	‘Umbubu’
AAT	‘Kabulupusa’, ‘Karoina’, ‘Mayalopa’, ‘Sar’
ABBT	‘Giant Kalapur’, ‘Yawa 2’
Unkown	‘Fei’

Source: [10].

Table 1.
Musa cultivars by genomic classification.

recorded a concentration of 12.7 mg/100 g FW for vitamin C that was almost threefold than 'Williams' (4.5 mg/100 g); a β-carotene concentration of 96.9 μg α-carotene/100 g and 104.9 μg α-carotene/100 g, while 'Williams' averaged 55.7 μg β-carotene/100 g and 84.0 μg α-carotene/100 g. 'Apple' bananas were also reported to have more phosphorus (P), calcium (Ca), magnesium (Mg), manganese (Mn) and zinc (Zn) than 'Williams' [10]. Similar data for fully ripe banana fruit (**Table 2**) were reported by the United States Department of Agriculture [23]. Other nutrients implicated to be present in cultivars of *Musa* spp. includes biogenic amines and polyphenols.

2.1 Carbohydrates

Banana and plantain are known to contain sugars, starch, fibre and cellulose compounds especially in its pulp. The peel portion of banana and plantain are rich in fibre. In banana fruit, inherent starch accumulates during development, with minimal changes in the principal carbohydrate metabolites observed during the preclimacteric phase [24]. Subsequently, the fruit starch is converted to sucrose, glucose and fructose as senescence sets in and progresses. Ripening in banana generally involves a decrease in starch concentration from 15 to 25% to less than 5% in the ripened pulp, together with an additional increase in sugar content [25, 26]. At the onset of senescence, sucrose is the predominant sugar, with glucose and fructose predominating as ageing sets in [27]. The concentration of sugars in banana and plantain is associated with respiratory climacteric stage [1]. Starch conversion to sucrose is catalysed by activity of sucrose phosphate synthase, while acid hydrolysis causes starch conversion to non-reducing sugars from sucrose. It was observed that harvest maturity largely affects the conversion of starch to sugar. Changes like these have been reported in both diploid (*Musa* AA) [28] and triploid (*Musa* AAA) banana fruits [29]. Similarly, during the ripening stage of dessert banana, starch is completely broken down, unlike for plantains where starch is not totally broken down [30]. Due to the presence of pectin in banana, it was reported that consumption of the fruit can mitigate intestinal diseases [1]. Furthermore, green banana produces antidiarrheal activity in children which will help to fight against the incidence of diarrhoea, one of the main causes of high mortality and morbidity in children of third world countries. Research further revealed that low fasting blood glucose and glycogenesis in the liver can be increased due to presence of fibres in banana fruit [1]. Dessert and cooking banana in their ripe state are reported to be rich in resistant starch (RS), while at their unripe state, the fruit contains mostly digestible starch [31].

2.2 Protein and Amino Acids

In the works of John and Marchal [32], whole nitrogen in 'Cavendish' pulp has been reported to be 210 mg/100 g (FW) and 750 mg/100 g (DW). The protein signified a total nitrogen content of about 60–65%. This is in agreement with what was reported by the USDA [23], wherein the protein content for *M. acuminata* was 1.09 g/100 g (FW). John and Marchal [32] found an increased protein value of 4–7 g/100 g (DW) and 1.3–1.8 g/100 g (FW) upon development of 'Cavendish' banana, and also for 'Dwarf Cavendish' from 4 to 8 g/100 g (FW), with the concentration increasing as ripening progresses. Unripe bananas are rich in proteins, with chitinase enzymes being the most abundant protein [32]. During ripening of bananas, starch phosphorylase, malate dehydrogenase and pectate lyase are accumulated. Dopamine, a water-soluble antioxidant reported in both pulp and peel of 'Cavendish' banana is one of the catecholamines that suppress the oxygen

Nutrient/content	Amount/value
Water (g)	74.91
Energy (kcal)	89.00
Protein (g)	1.09
Total lipid (fat) (g)	0.33
Carbohydrate, by difference (g)	22.84
Total dietary fibre (g)	2.60
Total sugars (g)	12.23
Calcium (mg)	5.00
Iron (mg)	0.26
Magnesium (mg)	27.00
Phosphorus (mg)	22.00
Potassium (mg)	358
Sodium (mg)	1.00
Zinc (mg)	0.15
Vitamin C, total ascorbic acid (mg)	8.70
Thiamine (mg)	0.031
Riboflavin (mg)	0.07
Niacin (mg)	0.67
Vitamin B-6 (mg)	0.37
Folate, DFE (μg)	20.00
Vitamin B-12 (μg)	0.00
Vitamin A, RAE (μg)	3.00
Vitamin A (IU)	64.00
Vitamin E (α-tocopherol) (mg)	0.10
Vitamin D (D2 + D3) (μg)	0.00
Vitamin D (IU)	0.00
Vitamin K (phylloquinone) (μg)	0.50
Fatty acids, total saturated (g)	0.11
Fatty acids, total monounsaturated (g)	0.03
Fatty acids, total polyunsaturated (g)	0.07

Source: [23].

Table 2.
Nutritional and biochemical composition of Musa acuminata Colla per 100 g.

uptake of linoleic acid [33]. Similarly, various bioactive amines including putrescine, spermidine and serotonin are reported to be present in high concentrations in banana. In addition, bananas have been found to contain physiologically relevant amounts of biogenic amines, nitrogenous compounds that include serotonin, dopamine and norepinephrine that vary relative to the ripening cycle, as well as the cultivar-dependent phytosterols cycloeucalenone, cycloeucalenone, cycloeucalenol, cycloartenol, stigmasterol, campesterol and β-sitosterol [33]. Bananas have some potential health benefits for cancer, cholesterol metabolism and related markers of cardiovascular disease risk.

2.3 Vitamins

Dessert and cooking banana contain different forms of vitamins in varying concentrations among the known cultivars worldwide. According to the reports of USDA [23] and Wills et al. [34], the vitamin C levels for 'Cavendish' banana estimated using high-performance liquid chromatography (HPLC), ranged from 2.1 to 18.7 mg/100 g (DW/FW), which however, varies considerably among different cultivars. The average vitamin C (**Table 2**) content for 'Dwarf Brazilian' (*Musa* AAB 'Santa Catarina Prata') was found to be 12.7 mg/100 g and 4.5 mg/100 g for 'Williams' [13]. These results agree with the report of Wenkam [35], who reported vitamin C values of 5.1 mg/100 g (DW/FW?) for 'Williams' and 14.6 mg/100 g (DW/FW?) for 'Dwarf Brazilian' banana cultivar.

Dessert banana contains substantial levels of provitamin A carotenoids (PVAC), but few cultivars with orange- or yellow-coloured pulp are known to have higher concentration of carotenoids [15]. Vitamin A deficiency has been reported to be a public health concern identified in almost 118 countries in the world, with highest prevalence in Asia and Africa, as their diets are mainly cereals and tubers [1]. Researchers from Australia (Queensland University of Technology) have concocted Cavendish banana with high amounts of β-carotene, a precursor of vitamin A. The carotenoids mostly found in fully developed bananas are lutein, α- and β-carotene. The fruit pulp is also rich in carotenoids, while the peel contains low amounts [36]. It is reported that during ripening the amount of carotenoids increase [20, 34]. Similar observation was reported by Kanazawa and Sakakibara [37], which contradicts the report of Gross and Flugel [38] who found carotenoid content decreasing during initial stage of ripening. As can thus be seen, different cultivars of *Musa* spp. contain different amounts of carotenoids. Banana and plantain fruits with orange flesh are rich in VAC [38, 39]. One variety of banana, 'Karat' of Micronesia, was reported to accumulate β-carotene of about 2230 mg/100 g [39].

2.4 Minerals

Banana and plantain are very rich in K, an essential element for maintaining human blood pressure and for proper functioning of the heart [40]. The fruit is also rich in Mg, Fe, Cu and Mn [20]. In the works of Pareek [10], the average K content for Hawaii's bananas ('Dwarf Brazilian' and 'Williams') were reported to be 330.6 mg/100 g (FW). Similarly, it was reported that fruits cultivated in Tenerife, were observed to contain a K content of 5.09 mg/g (FW), P content of 0.59 mg/g (FW), Ca content of 0.38 mg/g (FW) and Mg content of 0.38 mg/g (FW) [10, 41], though it was reported by the authors that the area of origin had a major effect on the occurrence of the minerals. Varietal differences had no effect on concentration of minerals present except for Fe. In the works of Forster et al. [42], differences were observed in the mineral content of bananas grown in both Ecuador and Tenerife. High Na, K, Mg and Fe contents were found for bananas grown in Tenerife, while high Ca, Cu, Zn and Mn contents were reported for bananas grown in Ecuador. This difference was attributed to agricultural practices, geographical location and soil composition [42]. Mineral composition of banana samples according to degree of ripeness was reported for the fruits obtained from Nigeria: 73.47% ash, 0.68% Zn, 0.146% Mn for unripe samples; 77.19% ash, 0.80% Zn, 0.271% Mn for ripe samples and 79.22% ash, 0.78% Zn for overripe samples [43]. Similarly, the peel of banana cultivars obtained from Cameroon contained relatively high minerals: K (50.0 mg/g DW), P (22.2 mg/g DW), Mg (11 mg/g DW) and Ca (18 mg/g DW) [44]. Generally, bananas contain low amounts of Ca, however, Micronesian cv. 'Krat' is relatively high in Ca [39].

3. Banana phytochemicals and bioactives

Phytochemicals have been reported to be an immense source of anticancer medications and chemopreventive agents [45]. These plant chemicals exert some of their actions through interactions with essential enzymes that regulate the activities in genes. Banana contains various bioactive compounds such as phenolics, carotenoids, alkaloids, glycosides, phlobatannins, tannins, terpenoids, saponins, steroids, biogenic amines and phytosterols, which are highly desirable in diet as they exert health beneficial effects [11, 32, 46]. These composites are helpful in protecting the body against oxidative stress due to their antioxidative activities [47], controlling gene expression in cell proliferation and apoptosis and important in controlling blood pressure [48]. The incorporation of banana pulp and peel in various food products could add value since they have health benefits [47]. Thus, banana pulp and peel can be used as natural sources of antioxidants and pro-vitamin A. Banana peel is reported to have higher antioxidant capacity than banana pulp [49–53]. Furthermore, phenolic content of banana peel was higher compared to other fruits such as avocado, pineapple, papaya, passion fruit, water melon and melon [50]. However, it is recommended that to effectively recover and utilise phenolic compounds from banana peels, it is important to evaluate its chemical profile, factors affecting the levels of phenolic compounds in the peels such as antinutrients, and potential use of these compounds as food ingredients or nutraceuticals. It is important to understand how these bioactive compounds found in fruits and vegetables limit or prevent oxidative stresses as a free-radical scavengers or metal-chelating agents. In the report of Liu [53], it was emphasised that there has to be a balance between oxidants and antioxidants for normal functioning of the body cell and/or sustaining optimal physical condition in the human body. Too much oxidants in the human body result in damage to the biomolecules such as proteins, lipids carbohydrates and DNA. Hence, to understand the mechanism of action of antioxidant, it is imperative to understand the formation of free radicals and their ability to damage macromolecules and nucleic chains.

Phenolic compounds have been implicated to be present in banana fruits. Although, banana peels contain more tannin compared with its pulp, tannins in the fruit confer an unpleasant astringent taste on the fruit. The astringency in ripe fruit is reduced, which is associated with a change in the structure of the tannins, rather than a reduction in their levels, as they form polymers [28]. When banana fruit is cut, oxidative browning occurs due to the presence of polyphenols. Report of different studies has shown that banana peels of different cultivars contain varying concentrations of total phenolic compounds (TPC). In the works of Nguyen et al. [54], it was reported that total phenolics, flavonoids and antioxidant activity of banana pulp and peel flours, Cv. 'Kulai Hom Thong' was shown to contain 3.0 mg of gallic acid equivalent (GAE)/gFW, while 'Kulai Khai' was reported to contain 0.9 mg of (GAE)/gFW. Similarly, banana cv. 'Pisangmas' from Malaysia was reported to contain TPC ranging from 0.24 to 0.72 mg GAE/g FW, depending on the extraction method [32]. Sulaiman et al. [52], also reported significant differences in the antioxidant activity, total phenolic and mineral contents of eight Malaysian banana cultivars. Flavonoids epicatechin and myricetin 3-O-rhamnosyl-glucoside were identified in flour of organic acid pretreated "Mabonde", "Luvhele" and "M-red" cultivars at different concentrations [55]. Authors Bennett et al. [56] and Borges et al. [57] also reported the presence of catechin and gallic acid in pulp and peel of ripe and unripe banana cultivars. Similarly, plantain a banana cultivar belonging to the AAB, ABB or BBB group [58] have also been reported to contain high concentration of hydroxycinnamic acids (ferulic acid–hexoside with 4.4–85.1 μg/g DW) in its pulp [32]. Plantain peels are rich in flavonol glycosides and rutin ranging from 242.2 to 618.7 μg/g DW.

Polyphenols are extremely diverse group of secondary metabolites, having sweet-smelling ring with one or more hydroxyl groups. Polyphenols have large range of structures and functions and can be classified as subgroups of flavonoids, phenolic acids, tannins, stilbenes and coumarins. These secondary metabolites are very essential in the metabolism, reproduction and growth of plants. Polyphenols also protect plants against pathological parasites, predators, fungal infections and viruses [53].

3.1 Banana volatiles

Tropical flavours including coconut, mango, mandarin as well as the combination of fruit and vegetable flavours are gaining popularity, with the African marula fruit and mangosteen being strong super fruit contenders [59]. Banana fruit flavour has been attributed to the presence of esters with inherent alcohols which contribute to flavour enhancement [60]. Alcohols and insignificant carbonyl composites present in banana are called green and woody notes [61], while the ester fraction contributes to fruity notes [62–64]. The presence of esters cause the sweet-smelling profile in ripe bananas, while that of unripe banana is determined by the presence of pentyl and hexyl alcohols, aldehydes and ketones [65]. Components of the fruity notes present in banana fruit includes 3-methylbutyl acetate, isoamyl butanoate and isoamyl isovalerate [66–68]. Esters constitute a major fraction of emitted volatiles from fresh banana fruits [64]. Esters can also be used to differentiate cooking bananas from desert bananas; in that cooking bananas lack esters, whereas the same form a major component of flavour present in desert bananas [69].

Aroma in banana fruit is characterised by the presence of various volatile compounds varying in concentration among cultivars [70, 71]. Pino [72] reported the presence of 250 volatiles in fresh and processed banana products, though few of these volatiles have been isolated as flavour contributors. Essential components affecting taste of banana fruit includes D-glucose, D-fructose and sucrose for sweetness, while citric, L-malic, oxalic and succinic acids have been implicated for sourness [65, 73]. Determination of volatiles that has unique character of the fruit is important as it produces the principal characteristic flavour of the fruit [74, 75]. The most appealing property of banana required by most consumers apart from their nutritional and health benefits is the flavour [76, 77].

3.2 Nutrigenomics of banana nutrients

With the ever changing nutrition-related health problems in developing economies, there is a gradual shift in nutrition research that focuses on how nutrition can be maximised in maintaining homeostasis at the cellular, tissue, organ and system level of the body [75]. This, however, requires the understanding of nutrient interactions at the molecular level. Nutrigenomics is the research into nutritional genomics, which also include nutrigenetics. In the works of Neeha and Kinth [78], nutrigenomics is defined as the study of the interaction between nutrients and genes, proteins and metabolic processes such as DNA and RNA synthesis and glycogenesis. Nutrigenomics focuses on the effects of nutrients on genome, proteome and metabolome as well as the interactions among these nutrients and nutrient-regimes in the body [78]. Through the application of molecular biology and genomic tools, researchers have identified genes responsible for the production of nutritionally significant proteins such as digestive enzymes, transport molecules and cofactors at their site of use [79]. Studies on genetic improvement of banana fruit is advancing at a rapid pace, using modern biotechnology which includes genetic engineering. Other programmes such as the use of banana as edible vaccine delivery system and biofortification of bananas to increase their β-carotene, α-tocopherol and iron contents are on the way [79]. These improvements will be most beneficial for regions of the world that consume bananas as their major staple. However, genetic improvement of banana fruit is a major challenge as cultivated banana fruits are basically sterile or possess low fertility with conventional breeding, though possible in delivering a few acceptable cultivars [79]. In the WHO [80] guideline on vitamin A supplementation in infants and children 6–59 months of age, about 19 million pregnant women and 190 million preschool age children from parts of Africa and South-East Asia were reported to be affected by vitamin A deficiency (VAD). Similarly, VAD is reported to be responsible for about 6% of child mortality below the age of five in Africa and 8% in South-East Asia [79]. Some banana cultivars have been implicated for the presence of dietary provitamin A carotenoid (PVAC) due to their characteristic orange-coloured fruit flesh. Carotenoid composition of the PVAC implicated banana cultivars has shown the presence of *trans*-α-, *trans*-β-, *cis*-β-carotene and lutein [21]. These notable differences in PVAC composition of the fruit could have significant consequences on the nutritional profile of banana varieties [79]. Banana bioactive compounds have potential for preventing various diseases when used as an ingredient in the food industry [81, 82].

4. Utilisation of banana bioactives as nutraceuticals and food ingredients

According to the Science Forum, nutraceuticals is defined as a "diet supplement that delivers a concentrated form of a biologically active component of food in a non-food matrix to enhance health" [83]. Anyasi et al. [58] in their study further added that nutraceutical can also be extracted from a different product derived from the food and pharmaceutical industry, herbal and dietary supplement market, and the pharmaceutical/agribusiness and nutrition conglomerates. Raw banana shows higher amount of functional ingredients such as dietary fibre, resistant starch and total starch, which allows banana to impart health benefits to humans when incorporated in food products [84]. **Table 3** highlighted the effects of banana bioactive compounds as a value-added ingredient in food processing. It is important to understand fruit maturity during preparation of banana flour to produce desirable food products. Ripe banana can be considered for industrial processing, which could result to products that are comparable to those obtained from apple, juice, fruit drinks, fermented drinks, stewed fruit, puree, marmalade, jam, flakes, confectionery, pastry, sorbets and ice-cream. Raw bananas can be considered as a source for new food innovation and development for partial or preprocessed food products like snacks and breakfast cereals [82]. Mixed pulp and peel flour from green banana has higher ash, total fibre and total phenolics than traditional wheat flour [85]. The addition of banana flour increases the indigestible fraction and the content of phenolic compounds in spaghetti [86]. Crackers containing greater amount of green banana flour showed increased antioxidant capacity [87]. The influence of green banana flour as a substitution for cassava starch on the nutrition, colour, texture and sensory qualities of snacks was reported for raw banana flour [87]. In the study, increased nutritional value including dietary fibre, polyphenol content and antioxidant capacity of the snacks was noted. Unripe banana peel can be incorporated in a sponge cake without imparting negative effects on the sensory quality [88]. The application of banana by-products, an underutilised renewable food biomass with potential in food and nutraceutical industry as a means of promoting green

Products	Maturity/cultivars	Effects on antioxidant activity	References
Pasta	Raw/*Musa paradisiaca*	Increased indigestible fraction and total phenolic content	[86]
Sponge cakes	Raw/*Musa cavendish*	Yielded more polyphenols and exhibit high antioxidant capacity	[88]
Cassava snacks	Raw/Musa AAA *Cavendish*	Increased antioxidant activity, including ferric-reducing power and superoxide radical scavenging capacity	[87]
Banana muffins	Raw	Exhibit antimicrobial activity	[90]
Orange juice	Raw mango peel/*Musa acuminate Colla* AAA	Increased capacity to scavenge free radicals of orange juice	[93]

Table 3.
Use of banana bioactive compounds as value-added product.

technology was reported [89–91]. Banana by-products such as peels are readily available for use as a source of raw materials, as they are regarded as waste during processing of foods such as jams, chips and noodles for green technology industry. Since the discovery of banana as a fruit for human consumption, there are no reports in the literature which show that it contains hazardous phytochemicals. Therefore, banana by-products preparation for usage in the food industry does not require excessive treatment as compared with other fruits by-products with potent hazardous constituents [89]. Banana peel extracts are rich in antioxidant capacity using multiple antioxidant assays. These peels are helpful in exhibiting antimicrobial activity against a wide range of bacteria and fungi [92].

5. Health benefits associated with banana bioactives

Banana is a very common fruit in most continents of the world and is consumed essentially as food. It is the fifth most significant food source with respect to world trade. Banana has more than a few bioactives which include biogenic amines, phenolics, phytosterols and carotenoids [46, 93]. These compounds are of immense benefit to consumers due to countless positive effects they have on human health (**Table 4**). The positive effects of these compounds on human health is expected because they have antioxidative properties, hence they are efficient in reducing oxidative stresses. Banana pulp has been reported to have high anti-tumour and antioxidant potentials [57]. Consumption of bananas is advantageous to body muscles due to its high content of K. Banana is usually suggested for patients suffering from anaemia due owing to its high content of Fe. Banana is low in Na, hence it helps in regulating blood pressure [46]. The presence of syringic acid in banana was reported [92]. This compound has an antidiabetic effect and could be used in managing glycoprotein abnormalities [92]. The consumption of catechin rich banana can help build up resistance to oxidation of low density lipoprotein (LDL), brachial artery dilation, increase plasma antioxidant activity and fat oxidation [94]. The gallic acid in banana was reported to exhibit hepatoprotective effects [95]. Serotonin in banana helps to avoid depression by altering mood and calming the body. The consumption of carotenoid rich banana is also effective in the treatment of vitamin A deficiency disorders and chronic diseases [39]. Dopamine and ascorbic acid present in banana is useful in reduction of plasma oxidative stress and enhancement of resistance to oxidative modification of LDL [56, 96]. In many

Bioactive compounds	Uses	References
Phenolic compounds—gallic acid, catechin, epicatechin, tannins and anthocyanins, gallocatechin, epigallocatechin, quercetin, myricetin, kaempferol, ferulic, sinapic, salicylic, gallic, p-hydroxybenzoic, vanillic, syringic, gentisic and p-coumaric acids	Act as protective scavengers against oxygen-derived free radicals and reactive oxygen species responsible for ageing and various diseases	[56, 98–101]
Carotenoids—lutein, β-carotene, α-carotene, violaxanthin, auroxanthin, neoxanthin, isolutein, β-cryptoxanthin and α-cryptoxanthin	Act as antioxidants, especially in scavenging singlet oxygen, decreases the risk of certain cancers, heart problems and eye diseases; improves immunity	[102–105]
Biogenic amines—serotonin, dopamine and norepinephrine	Reduce the plasma oxidative stress and enhance the resistance to oxidative modification of low density lipoproteins; contributes towards the feelings of well-being and happiness; plays an important role in the human brain and body as a neurotransmitter with great impact on our mood, ability to concentrate and emotional stability	[106, 107]
Phytosterols—cycloeucalenone, cycloeucalenol, cycloartenol, stigmasterol, campesterol and b-sitosterol	Lowers cholesterol level in the blood and reduce its absorption in the intestine; act as immune system modulators and also have anticancer properties	[108–110]

Table 4.
Bioactive compounds present in banana and their utilisation.

animal trials, banana has been shown to be useful in the treatment of diabetes, due to its antihyperglycemic effect [97]. Banana is also utilised as a source of energy for sports athletes as it forms a valuable constituent in various energy drinks and dried banana bars [1]. Consumption of the fruit has also been used in the prevention of muscular contractions in athletes due to its vitamins, K and Mg contents [1].

6. Current trends in banana bioactive utilisation

A number of essential bioactive compounds in bananas have been reported by different researchers. Banana holds adequate quantity of valuable bioactive compounds for health promotion. Several studies have established and verified antioxidant activity of these compounds and efficaciously used bananas in treatment of diseases and promotion of wellbeing [46]. Bananas are being currently used to produce variety of food items which are of benefit to human health. Moreover, bananas are being composited with other food products to improve the micro and macro-nutrient values, especially for food low in micro and macro-nutrients [75, 97].

7. Conclusion

Bananas are cultivated and utilised at different stages throughout the globe because the fruit contains both therapeutic and nutritional properties. Banana is composed of a substantial amount of beneficial bioactives which are essential for health and disease prevention. Bioactive compounds (phenolics, biogenic amines and phytosterols) in bananas could be enriched through genetic engineering, while developing bio-fortified cultivars for improvement of micronutrients. Banana peel contains substantial amounts of dietary fibre and bioactives at various stages of maturation. Industrial utilisation of the fruit in variety of food products will reduce occurrence of health related diseases even as its use in genomics will mitigate the effect of micro nutrient deficiency in the body.

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Chapter 4

Banana Pseudo-Stem Fiber: Preparation, Characteristics, and Applications

Asmanto Subagyo and Achmad Chafidz

Abstract

Banana is one of the most well-known and useful plants in the world. Almost all the parts of this plant, that are, fruit, leaves, flower bud, trunk, and pseudo-stem, can be utilized. This chapter deals with the fiber extracted from the pseudo-stem of the banana plant. It discusses the production of banana pseudo-stem fiber, which includes plantation and harvesting; extraction of banana pseudo-stem fiber; retting; and degumming of the fiber. It also deals with the characteristics of the banana pseudo-stem fiber, such as morphological, physical and mechanical, durability, degradability, thermal, chemical, and antibacterial properties. Several potential applications of this fiber are also mentioned, such as the use of this fiber to fabricate rope, place mats, paper cardboard, string thread, tea bags, high-quality textile materials, absorbent, polymer/fiber composites, etc.

Keywords: banana, pseudo-stem, fiber, production, extraction, characteristics, applications

1. Introduction

In recent years, people have focused on forest preservation and finding a rational way to use agricultural and forest residues. This trend is caused by the rapid increase in consumption of wood fiber-based products, which may result in an illegal logging activity due to decreasing permitted wood resources. Additionally, the use of cellulose fiber from the forest and agricultural residues has many advantages, such as environmental friendliness, recyclability, and low cost or even free raw material. Statistically, the annual production of lignocellulose fiber from crops in the world was about 4 billion tons (i.e., 60% agricultural produce and 40% forest produce). Compared to other major commodities, the global annual production of steel was only 0.7 billon tons, while that of plastic was only 0.1 billion tons [1]. These data show us the high opportunity for the utilization of cellulose fiber.

Banana plants, which belong to the family of Musaceae, are native to the Malaysia-Indonesian region of South-East Asia. Bananas are widely produced and abundant natural resources in tropical and subtropical countries in the world [1–3]. The banana plants are considered as one of the world's most useful plants. Almost all the parts of this plant, for example, fruit, peel, leaf, pseudo-stem, stalk, and inflorescence (flower), can be utilized [3, 4]. They are used in several food and non-food-related applications, for example, as thickener, colorant and flavoring, macro- and micro-nutrient source, livestock feed, fibers, bioactive compound source, and organic fertilizers [4]. The banana leaf is frequently used in food processing (in some countries, e.g., Indonesia), food esthetic, food packaging, etc. The banana fruit itself is one of the most popular fruits and important diet due to its high nutritional content [5], thus it becomes a valuable commodity all around the world. The banana pseudo-stem has also been considered for use as pulp and paper raw material, fiber for textiles, and filler or structural reinforcement in composites materials [6–10]. Additionally, all parts of the banana plant have some medical added values, such as the flower can be cooked and consumed by diabetics, bronchitis, dysentery, and ulcer patients. The banana pseudo-stem sap can be orally taken or externally applied for stings and bites. The young leaf can be used for skin irritations (as a poultice). The roots, ashes of leaves, peels, and seeds also can be used for medicinal purposes in some countries [11]. In recent years, banana fruits have been the fourth most important fruit crop produced in the world. Approximately, 72.5 million tons of banana fruit are produced yearly in the world [2]. The fruit can be consumed directly (after ripe) or processed into other products, for example, dried fruit, smoothie, flour, ice-cream bread, etc. [5]. The flower bud can also be processed into a dish.

The most widely known banana plant species for its fiber is Abaca (*Musa textiles*). Its fiber is highly important among the leaf fiber group, whereas the most common banana that is consumed by humans is a member of *Musa acuminata* species [12]. Figure 1 shows the photograph of banana tree and its several parts. The pseudo-stem of banana plant is the stem of banana plant that provides and transports nutrients from the soil to the fruits. This pseudo-stem will be cut and become waste biomass after the banana fruit is ripe and harvested, because the banana plant is unusable for the next harvest [1, 12, 13]. For every ton of banana fruit harvested, about 100 kg of the fruit is rejected (i.e., rotten fruit) and approximately 4 tons of biomass wastes (e.g., leaf, pseudo-stem, rotten fruit, peel, fruit-bunch-stem, rhizome, etc.) are produced. This means, for every cycle of banana fruit production, four times of biomass wastes are also produced [13]. Based on another literature, it can be estimated that one hectare of banana farm could produce approximately 220 tons of biomass wastes [12] (**Figure 1**). These wastes are usually disposed of by the farmer into lakes and rivers or simply burned. The banana tree wastes if not properly managed can cause problem to the environment, because if they are dumped in wet conditions or burned can produce greenhouse gas, which can cause a problem to the environment [12]. It is believed that this crop waste can be used in a more rational way, namely, as a source of cellulose fiber for further applications [9].

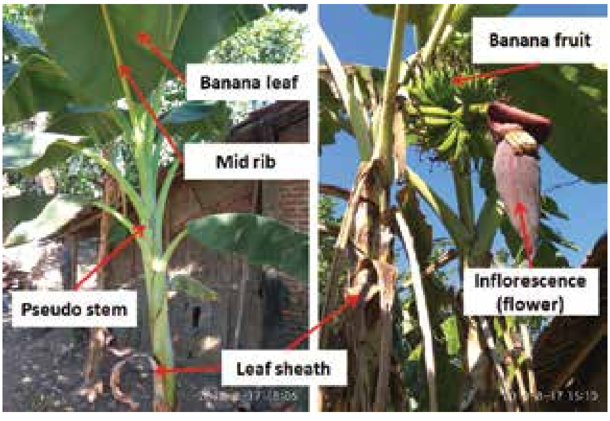

Figure 1.
Several parts of banana tree (photos were taken on August 17, 2018).

The pseudo-stem is a part of the banana plant that looks like a trunk, which consists of a soft central core and tightly wrapped up to 25 leaf sheaths. These leaf sheaths unwrap from the stem and transform to recognizable banana leaves when they have matured. The height of banana plant can reach approximately 7.5 m and since the leaf sheaths grow from the base of the plant, some of the leaves, on the inner side, have approximately the same length of the tree. Whereas the outer side leaves, which grow later, are shorter. The width of the banana leaves can reach approximately 30 cm [14].

2. Production of banana pseudo-stem fiber

The pseudo-stem fiber of banana plant is like the pineapple leaf, sisal, and other hard fibers, though the pseudo-steam fiber is a little more elastic. The major uses of banana pseudo-stem fiber are in making specialized and high-quality sanitary products such as baby pampers, textiles, and papers such as banknotes. The banana pseudo-stem fiber can also be used for ropes such as marine rope since this fiber has good resistance to sea water and has buoyancy properties. Other uses of this fiber are for making coffee and tea bags, filter cloths, as reinforcement fibers for plaster, disposable fabrics, and light-density woven fabrics. According to the literature, the production of Abaca (*Musa textiles*) fiber in the world has reached around 100,000 ton/year. The production in the year 1960 was also near this amount (i.e., 97,000 ton/year), whereas in the year 2002, the production of Abaca was about 99,320 ton/year. **Figure 2** shows the data percentage of banana production across the world in 2010.

2.1 Plantation and harvesting

The banana plant has a shallow rooting system in which the pseudo-stems sprout vertically. As it develops, a single plant may produce about 25 of these pseudo-stems, which mature at different times. When the plants are 18–24 months old, the outer pseudo-stems are already mature and ready to be harvested. Then, about three or four pseudo-stems are stripped at a period of 6–12 months based on the rate of growth of the pseudo-stem. When the flower is out, the pseudo-stems are completely ready for harvesting. Furthermore, the shaft is cut off below the inflorescence with a knife or sickle attached to a long pole and then the pseudo-stems are cut at their base. Based on the extraction methods, the pseudo-stems can be either

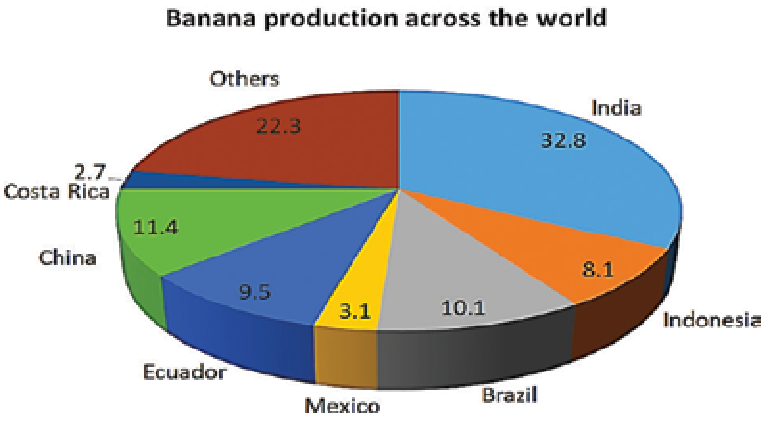

Figure 2.
Percentage data of banana production across the world in 2010 [15].

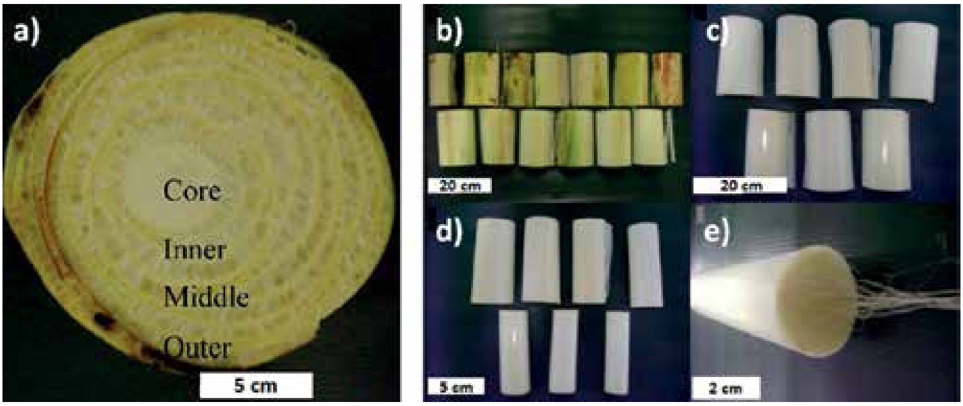

Figure 3.
(a) Banana pseudo-stem trunk cross section and its parts: (b) outer parts; (c) middle parts; (d) inner parts; and (e) core parts [16].

stripped/extracted of their fibers in situ or by using a decorticating machine [14]. The leaves are variable in length, the outer side leaves are shorter than the inner side. **Figure 3** shows the cross section of banana pseudo-stem and its parts.

2.2 Extraction of fiber

Fibers from the banana pseudo-stem leaves can be extracted by a decorticator machine. It is a machine used to strip bark, skin, wood, stalk, and grain. The extraction process is conducted as soon as the pseudo-stem's leaves are cut. The common method in practice is a combination of water retting and scraping. The first step, called tuxing, is separating the fiber bundles from the remaining parts. Tuxing can be done either manually or mechanically using machine [17]. The leaves are stripped from the cut pseudo-stems. Afterward, a knife is put at the butt end between the outer and middle layers of the leaf shaft, and then the outer part is held firmly and pulled out. The width of fiber bundles that resulted from this tuxing process is approximately 5–8 cm and is the same as the length of the leaf. The second step is to remove the gum or non-fibrous and any residual components contained in the fibers after the tuxing process [14]. Furthermore, the fibers are then thoroughly washed and dried. These processes demand considerable skill and patience. In general, only 11 exterior leaf sheaths in the banana pseudo-stem that can be extracted for its fibers. The fibers inside the interior sheaths have poor strength, and peeling of these fibers is found to be difficult due to their brittleness and poor strength [18].

One of the authors (A. Subagyo) has developed a decorticator machine, which could be used effectively by an average village artisan or an agriculturist for the extraction of fiber from banana pseudo-stem. The schematic diagram of the decorticator machine developed by Subagyo is shown in **Figure 4**. The decorticator machine consists of a rotating drum mounted on a shaft. On the circumference of the drum are mounted several blades which create a beating action as the drum is rotated by an electrical drive. As the drum rotates, the pseudo-stem is fed between the drum and backing plate or feeding roller. Owing to the crushing, beating, and pulling action, the pulpy material is removed when it is half way through. The pseudo-stems are slowly pushed from the drum and fall out to the conveyer belt, and eventually, the fibers are collected on the bucket. The next step is the degumming process of the fibers to remove foreign matter that are then washed and dried at room temperature of approximately 27–32°C. This machine can handle approximately two tons of dry fiber/day.

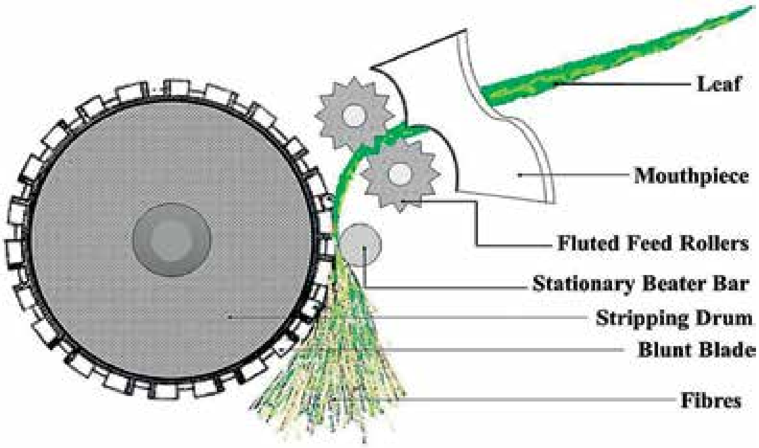

Figure 4.
Pseudo-stem fiber extraction machine.

2.3 Retting of banana pseudo-stem fiber

Retting of banana fiber is defined as the separation of the fiber bundles from the cortex or wood, which effects on partial digestion of the cementing material (such as lignin and hemicellulose) between the fibers in the bundles. This loosening of the fiber bundles is also due to the removal of various cementing tissue components. The retting of banana fiber is analogous to the general retting process, where two stages occur. The first stage is the physical stage in which the water is absorbed; then swelling happens, and some of the soluble substances are extracted. The second stage is the microbial stage, either aerobic or anaerobic by the action of fungi or bacteria, respectively.

Since retting process is basically a microorganism process, several factors such as: microbiological agents (bacteria or fungi), nature of retting water, aeration, and macro-nutrients. Microbial growth on plant fibers usually results in tenacity loss, odor release, and various types of strains on the fiber substrates. Sometimes, a specific microorganism can grow on a living plant stem and produce brownish stains on the fiber, which are usually known as rust. According to Subagyo [19], the factors like temperature, length of retting time, type of chemical additives (e.g., magnesium oxide), and pure culture of microorganisms such as pectin-decomposing bacteria in the retting liquor can reduce the retting time by approximately 78%. The pseudo-stem retting time of 28 h was found to be quite sufficient, and the process was effective at a controlled pH between 6.8 and 7.4 with sodium carbonate, and at room temperature.

Retting is carried out to increase the mechanical properties of natural fiber, such as banana pseudo-stem fiber [20]. Fiber tenacity tests indicated that the extractive removal of pectin from pseudo-stem fiber through retting did not cause any significant change in the tenacity of the fiber except when over-retting had begun. Furthermore, analysis of decorticated and retted pseudo-steam fibers indicated that retting can significantly reduce hemicellulose and lignin that are present in the pseudo-stem fiber. It has been reported that the pulping process of retted natural fibers gave pulps with better strength and chemical properties compared to those of the unretted fibers [21].

2.4 Degumming of banana pseudo-stem fiber

Banana pseudo-stem fiber produced by decorticator machine contains a quite large percentage of gum and non-fibrous cell or parenchyma (approx. 30–35%).

These gums and cells are mostly not soluble in water and must be extracted before the fiber is mechanically spun into fine yarn count. It is a numerical expression which indicates whether the yarn is fine or coarse, and thick or thin. The unit of count is mass per unit length or length per unit mass of the yarn. These gums basically consist of arabans and xylans, which are soluble in the alkaline solutions. The basic degumming process steps are as follows: boiling the fibers couple of times in aqueous alkaline solution with/without agitation and pressure, and with/without reducing agents; second, washing the fibers with water for neutralizing; third, fiber bleaching with dilute hydrogen peroxide or hypochlorite; and fourth, fiber washing with water for neutralizing and oiling with a sulfonated hydrocarbon. Most of the processes involve caustic soda to treat the residual pectin, lignin, and gum. Although pseudo-stem fibers are commonly degummed by chemicals, there are also promising alternatives in retting (microbial degumming). Additionally, several literature studies have reported that the use of ultrasonic vibrations could speed up the degumming process [22].

3. Banana pseudo-stem fiber properties

3.1 Morphological properties

Optical microscopy examination of pseudo-stem fiber of banana plant revealed that it is a multicellular fiber, like other vegetable fibers. The cells in this fiber have a diameter of approximately 10 μm and an average length of 4.5 μm with L/D ratio of 450. The cell wall thickness of banana fiber was found to be 8.3 μm, which lies between that of sisal (about 12.8 μm) and ramie (about 11.5 μm). The structural and fracture morphology of raw and chemically treated banana pseudo-stem fiber has been investigated using scanning electron microscopy after coating with a thin layer of gold or iridium [19]. Banana pseudo-stem fiber has a scaly and cellular structure with vegetable matter intact, as shown in **Figure 5a** and **b**. The horizontal marks on the fiber surface are attributed to the bundle structure of the fibers, in which each bundle consists of several fibrils. The transverse section of the pseudo-stem fiber is shown in **Figure 5c** and **d**, which confirms the multi-cellular structure, whereas the structure of the raw fiber is shown in **Figure 5e** and **f**. As seen in the figure, the lumen is clearly seen in the cross section (indicated by arrow no. 2), as well as the fiber-cell walls (indicated by arrow no. 1).

The hollow structure of the banana pseudo-stem suggests that the fiber will have good insulation and absorbance properties. Treating the fiber with either alkali or acid may result in good quality of fibers. For example, the treatment of pseudo-stem fiber with different concentrations of NaOH has indicated that the surface morphology of the 5% NaOH-treated fibers was not much different from that of the raw fibers. The surface looked clearer due to the removal of some impurities and debris, though the fiber is not clearly visible. The fibers and their fibrils are clearly visible when the pseudo-stem fiber is treated with 10% NaOH.

3.2 Physical and mechanical properties

Banana pseudo-stem fibers have physical and chemical characteristics and other properties that make them good quality fiber. In terms of physical properties, it has been reported in the literature that the banana pseudo-stem fiber has good modulus of elasticity, tensile strength, and stiffness, which makes it a promising fiber material [1]. The appearance of banana pseudo-stem fiber is quite like ramie and bamboo fiber, but its spin ability and fineness are much better than that of ramie and bamboo. It

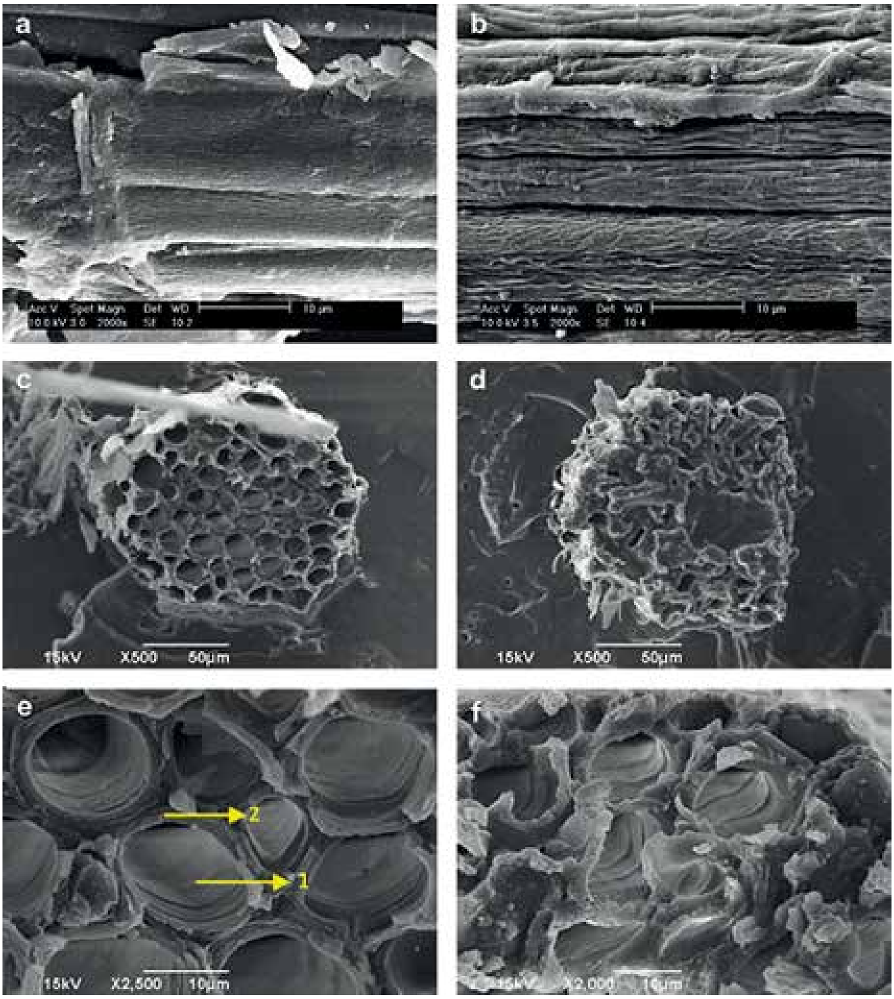

Figure 5.
SEM images of banana pseudo-stem fiber.

has average fineness of 2400 Nm. It is a strong fiber and has lower strain at break. Its appearance is quite shiny, which depends on the extraction and spinning processes. It has low density and strong moisture absorption quality. Its absorbance and release of moisture are quite fast. **Table 1** shows the physical and mechanical properties of banana pseudo-stem fiber in comparison with other types of plant/natural fibers. Additionally, studies of X-ray indicate that banana pseudo-stem fiber has a high degree of crystallinity with a spiral angle of about 15°. In the crystalline region, the molecules are packed more tightly. The acid and alkali-treated banana pseudo-stem fibers showed greater amorphous region than the untreated fiber.

3.3 Durability and biodegradability

Studies on the durability of banana pseudo-stem fiber have been carried out at the Center of Study for Natural Fiber and Natural Dyes (CSNFD) at the Department of Chemical Engineering, Concentration Textile Engineering, Universitas Islam Indonesia (UII). The studies showed that the durability of banana pseudo-stem fiber can stay up to 3 months of storage. However, if the storage period of the fiber is longer than 3 months, the strength of the fiber is considerably decreased.

Fibers	Width or diameter (μm)	Density (kg/m^3)	Cell L/D ratio	Microfibrillar angle (degree)	Initial modulus (GPa)	Tensile strength (MPa)	Elongation (%)
Banana pseudo-stem	80–250	1350	150	10 ± 1	7.7–20.0	54–754	10.35
Coir	100–450	1150	35	30–40	4–6	106–175	17–47
Pineapple leaf	20–80	1440	450	8–14	34.5–82.5	413–1627	0.8–1
Sisal	50–200	1450	100	10–22	9.4–15.8	568–640	3–7
Palmyra	70–1300	1090	43	29–32	4.4–6.1	180–215	7–15

Table 1.
Physical and mechanical properties of some plant fibers [23, 24].

Furthermore, banana pseudo-stem fibers are biodegradable, and thus can be categorized as environmentally friendly. Banana pseudo-stem fiber can be spun using almost any method of spinning, such as open-end spinning, ring-spinning, bast fiber spinning, and semi-worsted spinning.

The study of biodegradability of the banana pseudo-stem fiber can be done by burying the fiber in the ground. While buried in the ground, the growth of microorganisms plays a major role during the degradation process of fiber cellulose by secretion of enzyme cellulose, which results in the loss of tenacity. Based on the soil burial test, it was found that the banana pseudo-stem fiber loses strength rapidly when buried in the ground. The decrease of tensile strength after soil burial for 3 days is only approximately 21.8%, compared to that of sisal and jute, which is approximately 65.8 and 78%, respectively. Banana pseudo-stem fibers also lose strength and elongation conditions, the loss of fiber strength could be ascribed to the penetration of water molecules in the multicellular lignocellulose fibers. Swelling up of the fibers and, to some extent, loosening of the binding of the ultimate cells result in cell slippage when load is applied. Under wetting conditions, extension of untreated and degummed fibers is reduced by 6 and 11%, respectively.

3.4 Thermal properties

Thermogravimetric analysis (TGA) is carried out to analyze the heat stability or thermal degradation of banana pseudo-stem fiber. The TGA analyzer records the weight loss as a function of temperature with a resolution of 0.1 mg. The fiber samples (about 3–6 mg) were accurately weighed and randomly distributed in the sample pan. A small amount of sample was used to ensure the uniformity or reproducibility of the TGA result. The following is an example of TGA of banana pseudo-stem. The thermal degradation of the fiber started at a temperature of 25–700°C in N_2 environment at a constant heating rate of 10°C/min. Thermal degradation of the banana pseudo-stem fiber occurred in three stages.

The first stage of degradation was evaporation of moisture at a temperature range of 30–144°C [26]. As the fiber was continuously heated, the weight of the fiber decreased by releasing moisture and some volatile extractives. This is a common phenomenon that occurs in plant fibers, which makes the fibers become more flexible and collapse easily, and increases heat transfer [27]. Nevertheless, the moisture contained in the fiber cannot be completely removed due to structural resistance from the fiber and the hydrophilic nature of the fiber. In this first stage, the weight loss of the fiber was in the range of 5–10 wt%. The second stage was the degradation of hemicellulose. For banana pseudo-stem fiber, the hemicellulose

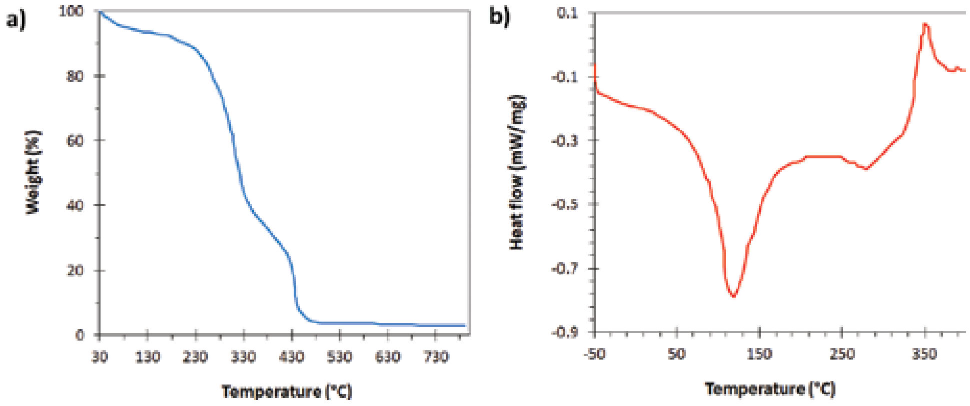

Figure 6.
(a) TGA curve and (b) DSC thermogram of banana pseudo-stem fiber [29, 30].

started to decompose at a temperature of approximately 178°C [26]. The lower stability of the hemicellulose is likely due to the presence of acetyl groups, which make the hemicellulose degrade much more quickly than the other components, for example, lignin and cellulose. The third stage was the degradation of cellulose, which occurred at a temperature of approximately 296°C. The last stage (that is, fourth stage) is the decomposition of lignin. Lignin is more difficult to decompose compared to other components. Generally, for any plant fiber, the decomposition of lignin occurred slowly in all ranges of temperature up to 700°C.

Nevertheless, for banana pseudo-stem fiber, there was a considerable lignin degradation peak that reached maximum degradation temperature of 501°C [20]. This was a result of broken protolignin bonds present in the fibers. This confirmed that the degradation of lignin happened in a wider range of temperature as compared to other components (e.g., hemicellulose, cellulose, and moisture) [28]. **Figure 6a** shows the TGA curve of banana pseudo-stem fiber. Moreover, **Figure 6b** shows the differential scanning calorimetry (DSC) thermogram of banana pseudo-stem fiber. According to the literature, the trend of DSC thermogram of the banana pseudo-stem is quite similar to that of other lignocellulosic fibers. The peak shown in the DSC (approximately 50–150°C) can be attributed to the heat required by the fiber to evaporate the moisture contained in the fiber. The range of temperature is in agreement with the TGA results, in which the first stage of degradation was evaporation of moisture at a temperature range of 30–144°C. Additionally, thermal conductivity of banana pseudo-stem fiber is found to be quite low at 0.0253 W/m^2 K, which suggests that these fibers could be used as good thermal insulations.

3.5 Chemical properties

In the past, many researchers were interested in the chemical constituents of plant fibers. It was found that plant fibers contain some of the following components [31]:

a. Fat and waxes, which are mostly found on the surface of the plants and can be extracted using benzene.

b. Pectin, which exists in water-soluble form as calcium and magnesium from galacturonic acid. These substances are converted into butyric and acetic acids during biological retting.

c. Hemicelluloses, which are amorphous short-chain polysaccharides and polyuronides. The polysaccharide hemicelluloses are chemically partly linked or intermingled with cellulose molecules.

d. Cellulose, which is the major constituent of the fiber.

e. Lignin, which is a short-chain isotropic and non-crystalline polymer made up of units derived from phenyl propane.

f. Ash content.

g. Aqueous extract, which is extracted by boiling the dewaxed fibers in water.

Table 2 shows the composition of constituents of banana pseudo-stem based on different literatures [17]. As shown in both of the tables, the banana pseudo-stem mostly consists of cellulose. Cellulose fiber can be considered as the most available natural, biodegradable, and renewable polymer that can be used in many applications (reinforcing materials, textiles, polymer matrix, and raw materials for paper) [32].

Additionally, there was a method reported in the literature [3] that showed the steps to deconstruct the banana pseudo-stem fiber to know the chemical composition of the fiber. The detailed steps of this method are exhibited in **Figure 7**. Step 1 is the determination of lipo-soluble extractive (LSE) content. Step 2 is determination of water-soluble extract (WSE) content. Step 3 is determination of pectin content. Step 4 is the determination of lignin content. Step 5 is the separation of cellulose-hemicellulose. The details about the determination procedure of these components have been explained in the literature [3].

Several methods can be used to extract cellulose fibers from their biomass sources, which are steam explosion treatment, alkali treatment, enzyme treatment, and liquefaction [24]. The focus of this chapter is the alkali treatment method. The properties of alkali-treated banana pseudo-stem fiber have been studied. The treatment of the fiber with 18% NaOH has enhanced the breaking elongation of fiber. This caustic treatment also resulted in length shrinkage, with the maximum shrinkage found to occur within 20 min of the alkali-treatment, after which there was only very little shrinkage. The length shrinkage has been found to be proportional to the weight loss. The weight loss is mainly due to the removal by caustic treatment of hemicellulose component and other substances. However, with an alkali-treatment, the banana pseudo-stem fiber also experienced a decrease in dynamic modulus. This decrease can be related to structural change caused by alkali treatment. The diameter of the fiber increased by the caustic treatment by 15–100%, which resulted in bundle fiber bulk improvement.

Sample	Cellulose (%)	Hemicellulose (%)	Lignin (%)	Extractives (%)	Ash content (%)	Moisture content (%)	Ref.
1	63.20	18.60	5.10	1.40	1.02	10.00	[31]
2	31.27	14.98	15.07	4.46	8.65	9.74	[33]
3	63.9	1.3	18.6	10.6	1.5	—	[34]
4	31.26	14.98	15.07	4.45	8.64	9.74	[7]
5	57	10.33	15.55	—	—	20.23	[35]
Average	49.33	12.04	13.88	5.23	4.95	12.43	

Table 2.
Components' composition of banana pseudo-stem (based on different literatures).

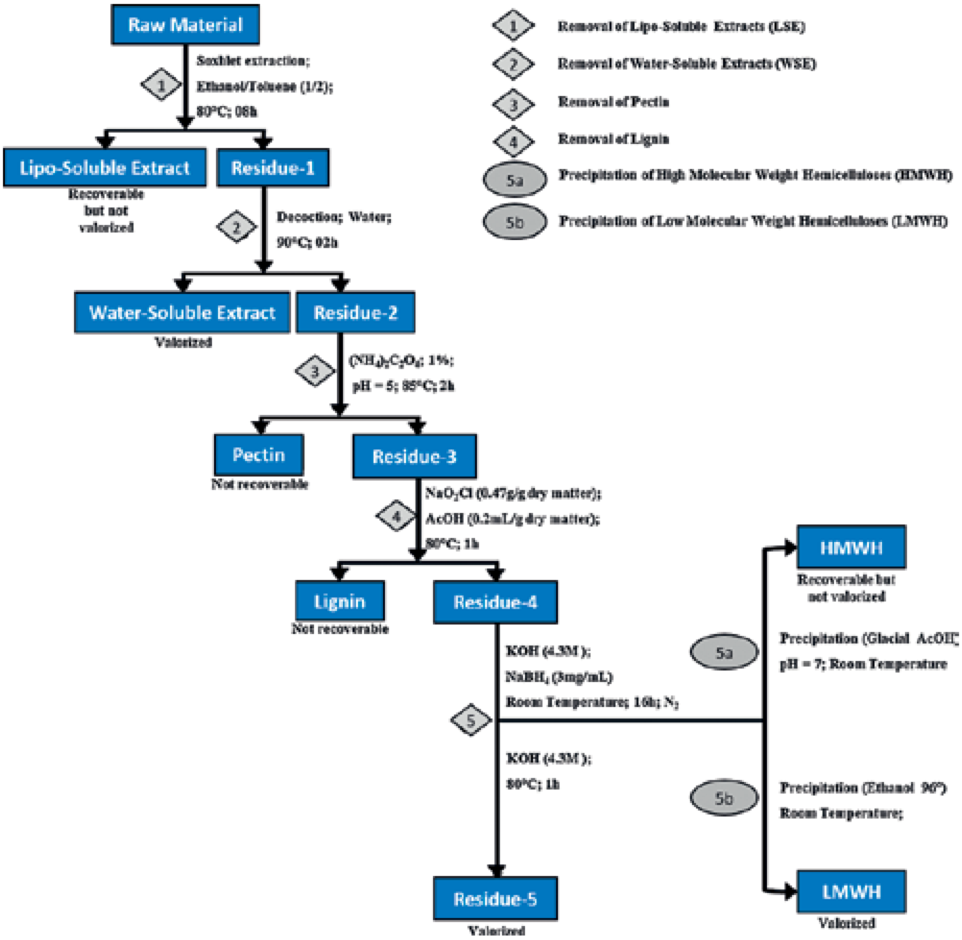

Figure 7.
Several steps of chemical deconstruction of banana pseudo-stem fiber [3].

The main problem to be encountered during wet processing of banana pseudo-stem fiber is the removal of lignin, residual gum, and other cementing materials, which interferes with the absorption property and thus leads to poor scouring, bleaching, and dyeing of the fiber. The exact structure of lignin is not clearly revealed, although it is generally regarded as a three-dimensional polycondensate of dehydrogeneration products of hydroxy and methoxy cinnamyl alcohols. Lignin is mainly composed of methoxyl, hydroxyl, and carbonyl groups.

Additionally, the physico-chemical properties of the banana pseudo-stem fiber were also studied. Infrared (IR) spectroscopy is probably one of the most widely used instrumental methods for investigating physico-chemical properties of textile materials. When a sample of organic compound is passed by infrared, certain frequencies are absorbed while others are transmitted through the sample. The IR spectrum is obtained by plotting the percentage of absorbance or percentage transmittance values against the frequencies. Fourier transform infrared spectroscopy (FTIR) was used to study the absorption peaks of banana pseudo-stem fiber. **Figure 8a–c** shows the FTIR spectrum of untreated, acid-treated, and alkali-treated pseudo-stem banana fiber, respectively. The appearance of absorption peaks was due to the presence of some functional groups.

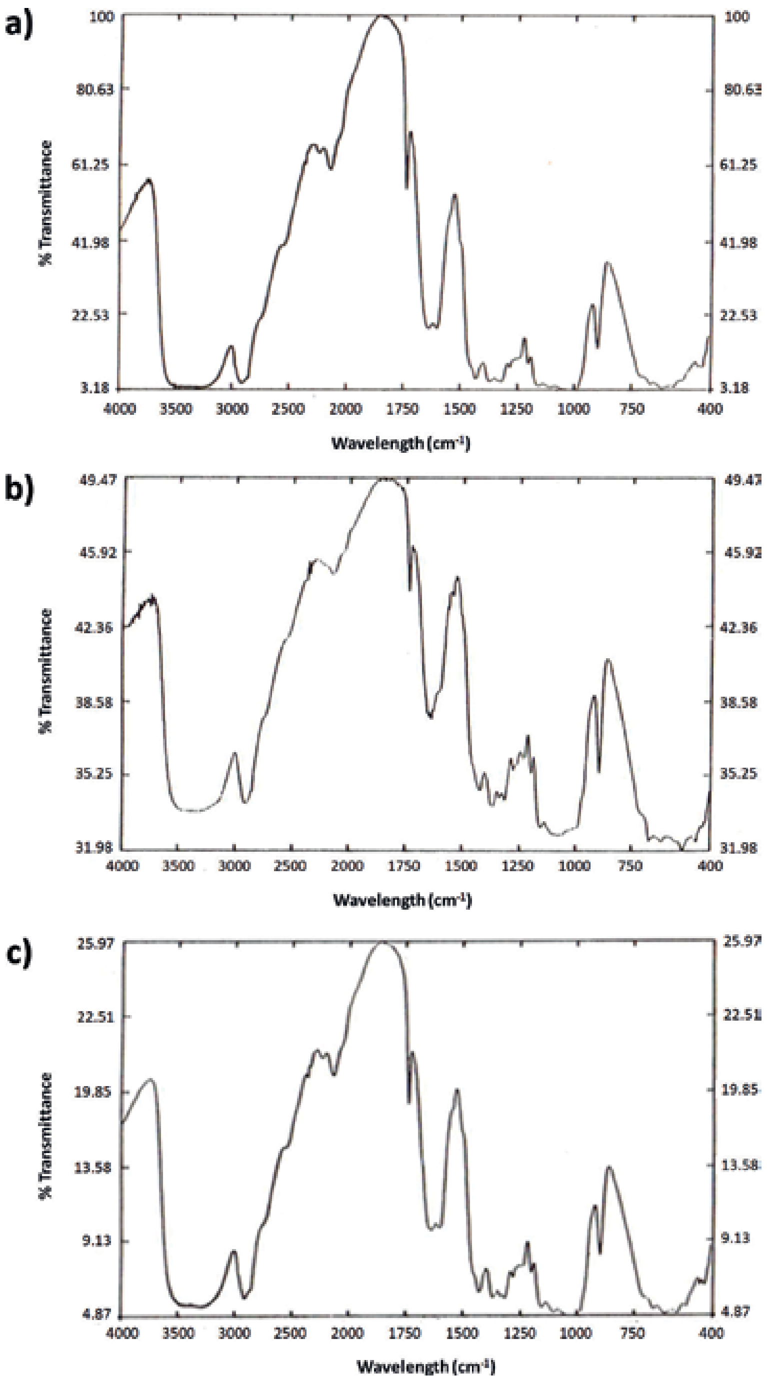

Figure 8.
FTIR spectrum of banana pseudo-stem fiber: (a) untreated banana; (b) acid-treated; and (c) alkali-treated.

3.6 Antibacterial test

Banana and banana pseudo-stem contain pathogenesis proteins, which possess antimicrobial properties [39]. The antibacterial activity of the banana pseudo-stem fiber can be analyzed using a shake flask test, according to Standard of Textiles Evaluation for antibacterial activity Part 3: Shake flask method, GB/T 20944.3-2008. Analysis of the effect of banana pseudo-stem fiber physical state on its

Plant fibers	**Moisture regain (%)**
Banana pseudo-stem fiber	9.8–12
Cotton fiber	7.75–9.50
Flax fiber	9.24–10.50
Ramie fiber	6.81–9.80

Table 3.
Moisture regain of textile fiber.

antibacterial properties can be done as follows. Untreated/raw cotton was used as the control sample, and the antibacterial/treated cotton was used as the test sample. The antimicrobial properties were determined by calculating the bacteriostatic rate using Eq. (1).

$$Y = \frac{W_t - Q_t}{W_t} \times 100\% \tag{1}$$

where Y is the bacteriostatic rate (%), W_t is the average colony-forming unit (CFU) per mm for the flask that contains the control sample after 18 h of contact, and Q_t is the average CFU/mm for the flask which contains the test sample after 18 h of contact. The extractives' effect on the microbial resistance properties of the banana pseudo-stem fiber can also be investigated. The growth condition of the bacteria in the flasks, which contains the unextrvacted and extracted fiber, is compared. The extractives' effect on the microbial resistance properties is evaluated by calculating the antimicrobial efficiency using Eq. (2). A negative number in the calculation result is represented as 0.

$$E = \left(1 - \frac{D_t}{D_0}\right) \times 100\% \tag{2}$$

where E is the antimicrobial efficiency (%), D_t is the average CFU/mm for the flask that contains extracted fiber after 18 h of contact, and D_0 is the average CFU/mm for the flask containing the untreated banana pseudo-stem fiber after 18 h of contact [37].

The microorganisms that can be used for the antibacterial test are *Staphylococcus aureus* (gram positive bacteria), *Escherichia coli* (gram negative bacteria), and *Candida albicans* (fungi). Nutrient broth and culture medium (agar) are used for the bacterial growth, whereas for the fungal growth, Sabouraud's culture medium (agar) is used. Additionally, there is a correlation between bacteriostatic rate and moisture regain of the natural fiber. The higher the moisture regain of a natural fiber, the lower the bacteriostatic rate. **Table 3** shows moisture regains (hygroscopicity) of different plant fibers. As seen in the table, the hygroscopicity of the banana pseudo-stem fiber is the highest among the others, whereas the ramie fiber has the lowest moisture regain.

4. Applications of banana pseudo-stem

As previously explained in the beginning, banana pseudo-stem usually becomes biomass waste once the harvest time of banana fruit is finished. Its disposal has become a major problem due to the amount of the waste. Therefore, researchers have started to extract the fibers and other components from the stem and used them to produce various value-added products. One of the most common banana pseudo-stem fiber products produced today is rope and cordage. The seawater resistance of the pseudo-stem fiber and its natural buoyancy characteristic have made a market for this fiber in the shipping cable manufacture. This fiber is also used to produce fishing nets, other types of cordage, mats, packaging, sheets, etc. **Figure 9** shows some value-added products made of banana pseudo-stem fiber. Additionally, in the Edo period of Japan (1600–1868), banana pseudo-stem fiber was used to make traditional dresses such as kimono and kamishimo. This fiber is usually used due to its light weight and comfort. Furthermore, banana pseudo-stem fiber is also utilized to produce cushion cover, bag, table cloth, curtain, and others [38]. Additionally, there are some potential uses of banana fibers, such as: to be used as natural absorbent, for production of mushroom, arts/handicrafts, string thread, paper cardboard, tea bag and high-quality textiles/fabric materials, currency note paper, and many other products. The use of banana fiber as natural absorbent also has promising potential to absorb oil spilling in oil refinery. It also can be used as absorbent in colored wastewater from the dyes of textile industry [39, 40]. Banana and banana pseudo-stem contain pathogenesis proteins, which possess antimicrobial properties [39]. The pseudo-stem can also be converted into bio-fertilizer [41]. It also contains high amount of cellulose and starch, and thus it can be utilized as feed for cattle [15]. Moreover, there have been numerous research studies that reported the use of banana pseudo-stem fiber in fabrication of polymer/fiber composites [17, 42].

Cellulosic cotton textile very easily catches flame, and it is very difficult to be extinguished. This problem of course poses a dangerous risk to life of human beings and textile products. Therefore, major efforts have been made in the past years to improve the flame retardancy of the cotton textile material by using many synthetic chemicals, which are available commercially. Phosphorous-based flame retardancy agents together with nitrogen-based compounds are the most effective combination that have been reported so far. However, there are some drawbacks such as high cost

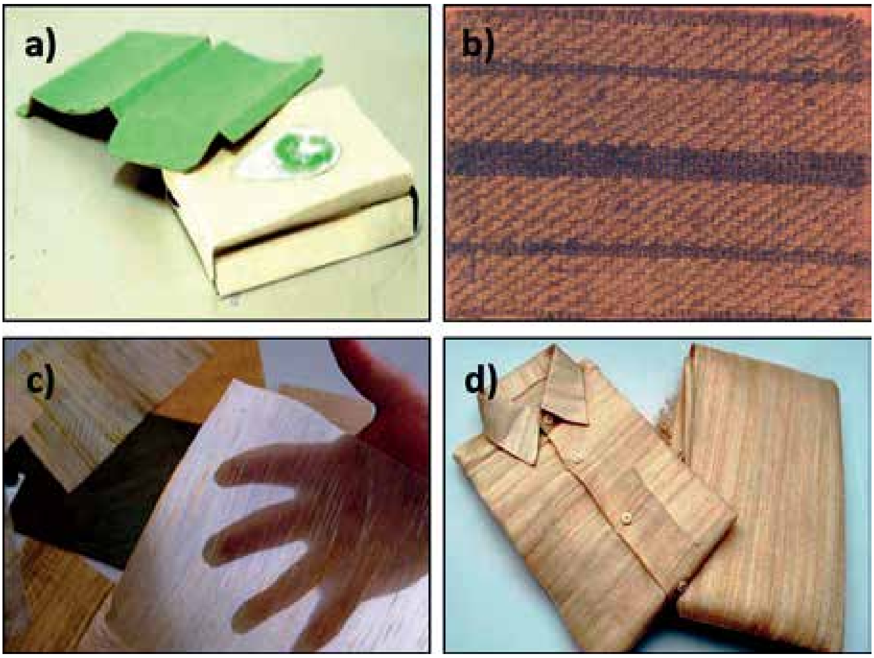

Figure 9.
Value-added products made from banana pseudo-stem fiber: (a) banana fiber package; (b) banana fiber mat; (c) banana sheets; and (d) banana fiber textile/shirt.

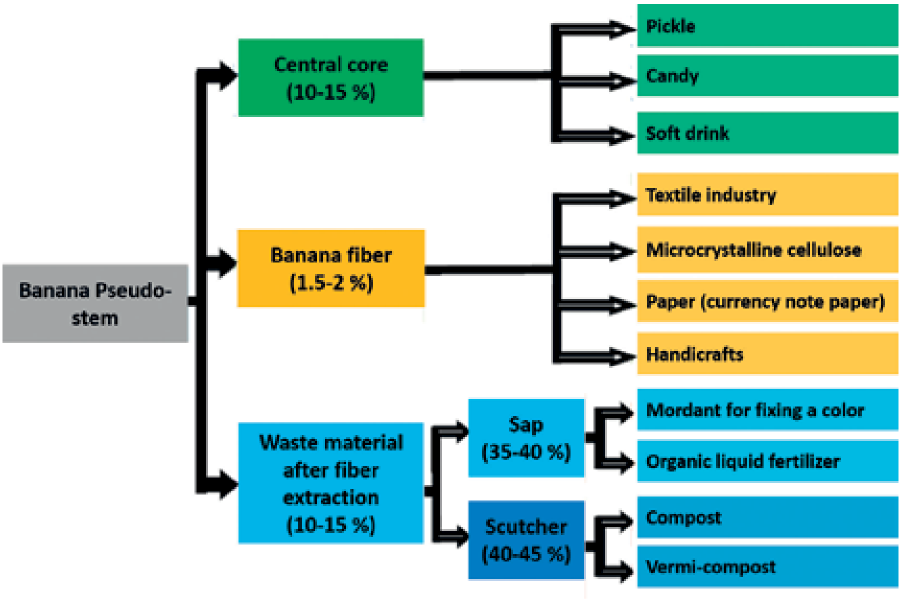

Figure 10.
Potential applications of components from the banana pseudo-stem.

and not environmentally friendly [43]. Hence, there is a growing trend that focuses on more cost-effective, environmentally friendly methods, and sustainable fire-retardant products. Several literature studies have been reported on providing fire retardancy to the cotton textile material by using natural products. One of them is using the waste banana pseudo-stem sap (BPS) [36]. Banana pseudo-stem sap (BPS) is a liquid that is extracted from the banana pseudo-stem. Additionally, there are many more potential applications of banana pseudo-stem components. **Figure 10** shows several value-added products made of components, which are derived from the banana pseudo-stem.

5. Conclusion

Banana plants are considered as one of the world's most useful plants. Almost all of the parts of this plant, for example, fruit, peel, leaf, pseudo-stem, stalk, and inflorescence, can be utilized. The banana fruit itself is one of the most popular fruits that is a valuable commodity all around the world. Nevertheless, banana pseudo-stem usually becomes biomass waste once the harvest time of banana fruit is finished. Therefore, researchers have started to extract the fibers and other components from the stem and used them to produce various value-added products. The fibers from the banana pseudo-stem can be extracted by a decorticator machine. The next processes are retting and degumming of the fibers. The fibers derived from the banana pseudo-stem can be made into several value-added products, such as rope, cordage, fishing net, mat, packaging material, paper sheets, textile fabrics, bag, table cloth, handicrafts, absorbent, polymer/fiber composites, etc. Additionally, other components derived from the banana pseudo-stem can also be used. The central core can be used for making pickle, candy, and soft drink, whereas banana pseudo-stem sap (BPS) can be used for mordant for fixing a color and organic liquid fertilizer, while the scutcher can be used for making compost and vermi-compost.

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Chapter 5

Banana Drying Kinetics

Adeyeye Samuel Ayofemi Olalekan

Abstract

Bananas (*Musa acuminata*) are one of the most important tropical fruits consumed worldwide by people of all age groups. Banana fruits are highly perishable, requiring preservation in some forms. Minimal processing, refrigeration and dehydration or drying are among the useful processes used in preserving banana fruits. Drying of banana fruits is used in reducing losses and improving food commercial value. Drying is the process of moisture removal due to simultaneous heat and mass transfer under controlled conditions. Drying as an old method of food preservation is widely embraced because it is simple, easy to operate and cost-effective. Drying also reduces bulkiness of banana through moisture loss which reduces the volume and eases handling and processing operations. This in turn reduces the costs of packaging, handling, storage and transportation. There are different drying techniques with different advantages and shortcomings. Agricultural produce have been dried for ages with natural and artificial methods to preserve them. The drying kinetics of banana is a complex phenomenon, and it is used in predicting the drying behaviour and for optimizing the drying parameters. This chapter assesses the models of drying kinetics in predicting the drying behaviour and in optimizing the drying parameters of banana fruits.

Keywords: banana, drying, kinetics, quality, shelf life

1. Introduction

Bananas belong to the genus *Musa* [1] and botanical members of berry [2, 3]. Banana chips are a snack produced from sliced dehydrated or fried banana or plantain. Dried bananas are also ground to make banana flour which has several food applications such as production of stiff dough called *amala ogede* in Nigeria and other West African countries. Singh et al. [4] and FAO [5] reported the worldwide production of bananas in 2012 to be 139.2 million tonnes. According to Singh et al. [4], world banana exports are projected to reach almost 17.9 million tonnes in 2011, and India led the world in banana production, producing around 18% of the worldwide crop of 139 million metric tonnes. It was also reported by Singh et al. [4] that more than 85% of global banana production was produced by small-scale farmers, providing an important source of food and income for the small farm households. In 2016, according to FAOSTAT [6], bananas and plantains were 148 million tonnes globally, with India leading and closely followed by China with a combined total (only for bananas) of 28% of global production. The Philippines, Ecuador, Indonesia and Brazil are other major producers accounting for 20% of the global banana and plantain production (**Table 1**).

Country	Banana	Plantain	Total
India	29.1		29.1
China	13.1		13.1
Philippines	5.8	3.1	8.9
Ecuador	6.5	0.6	7.1
Indonesia	7.0		7.0
Brazil	6.8		6.8
Colombia	2.0	3.5	5.5
Cameroon	1.2	4.3	5.5
Uganda	0.6	3.7	4.3
Ghana	0.09	4.0	4.1
Guatemala	3.8	0.3	4.1
World	113.3	35.1	148.4

Source: FAOSTAT [6].

Table 1.
2016 Production in millions of tonnes.

Because bananas are highly perishable, there is a need for dehydration of banana to reduce postharvest losses. Among the useful processes used to preserve banana fruits are minimal processing [7–9], refrigeration [10, 11] and dehydration or drying [12–16]. Drying of banana is a useful method to reduce postharvest losses [17, 18] and to improve commercial value of banana. Drying has become necessary to make them available all year round and at locations where they are not produced. In addition to preservation, the reduced weight and bulk of dehydrated banana products decrease packaging, handling and transportation costs [17, 18]. Drying banana can also lead to quality changes such as physical, sensory, nutritional and microbiological. Omolola et al. [19] reported that drying banana gives rise to low or moderate glycemic index (GI) products with high calorie, vitamin and mineral contents.

Drying is the process of moisture removal due to simultaneous heat and mass transfer under controlled conditions to reduce the bulkiness of the fruits [17, 18, 20–23]. It is one of the oldest methods of preservation and widely applied to banana fruits owing to its simplicity, ease of operation and cost-effectiveness. Besides these advantages, drying decreases the bulk of foods by reducing the volume which reduces packaging, handling and storage and transportation costs as well as ease of handling and processing operations [17, 18, 20–25].

Several researchers have carried out studies on drying of bananas, for example, solar drying [26], drying using vacuum [27], foam mat drying [28] and spray drying [29]. Dried banana is a food stock in ripe [30] or unripe maturation state [31]. The dehydration of banana results also in physical modifications as color change [32], shrinkage and porosity [33, 34] and texture [35, 36]. Based on their findings, important dehydration process variables that have influence on drying process and guarantee the obtainment of dried fruits with good quality have been done. Such parameters are appropriate cultivar, pretreatments and drying conditions [37–40].

A lot of research efforts are geared towards the study of drying kinetic of banana fruits. The drying kinetics are usually used to predict the drying behaviour and for optimization of the drying parameters of various foods [41, 42]. Therefore, the chapter focuses on the existing and emerging drying techniques and drying kinetics of banana.

2. Drying techniques

Drying banana is the process of moisture removal due to simultaneous heat and mass transfer under controlled conditions [18, 42, 43]. Drying is the most energy-intensive process in the food industry. Therefore, improving drying processes by reducing energy consumption, increasing efficiency of the drying process and providing high-quality products with minimal increase in economic input have become the goal of modern drying [44–46].

In drying of banana, convective drying in hot air is still the most popular method applied to reduce the moisture content of banana. However, the shortcomings of convective drying in hot air are very long drying period, high-energy consumption, contamination problems, low energy efficiency and high costs, which are not desirable for the food industry [47, 48]. But, the desire to reduce the above problems, as well as to achieve a fast and effective thermal process, led to the use of microwave and dielectric heating methods for banana drying [49, 50]. These drying methods have several advantages such as higher drying rate, shorter drying time, decreased energy consumption and better quality of the dried products when compared with the convective drying in hot air [51–53].

Drying methods are divided into natural and artificial methods of drying. The natural method of drying involves the use of energy from the sun to remove moisture from banana fruits. The major shortcoming of this method is that it depends on weather conditions and is highly inefficient [54]. Artificial method of drying uses mechanical devices to improve drying efficiency of the method [55]; this leads to products of better quality. In addition controlling of various factors involved in the drying process such as temperature, drying air flux and time of drying is also possible. Artificial drying is done with the help of mechanical or electrical equipment which improves efficiency.

2.1 Natural drying methods

2.1.1 Solar drying

Sun is as old as the universe itself and is an inexhaustible and free source of energy, utilized for drying of banana since ancient times. Solar drying can be classified into direct and indirect methods of drying.

2.1.2 Direct method

This is a traditional method which involves the sunlight to dry banana. Banana to be dried is left exposed to the sun for several days to achieve the desired moisture content. This is very common in developing countries where fuel is scarcely available to farmers due to high cost; open sun drying is the most popularly used method of drying since it is simple and only requires sunlight [56]. However, the major problems faced by open-air sun drying are insect infestation, dust and dirt contamination, long time for drying, overheating due to direct exposure, quality deterioration and low rate of transmission of heat due to condensation of the evaporated moisture [57]. In order to improve on the sun drying method, a simple form of solar dryer could be used to dry banana slices.

2.1.3 Indirect method

Indirect solar drying involves the use of solar dryer to overcome the problems encountered by the direct method of drying. Different types of indirect solar dryers are chamber type, chimney type and wind-ventilated dryers. In the indirect method of solar drying, the heat acquired by the system is used to heat the air that flows through the product to be dried.

2.2 Artificial drying methods

2.2.1 Convective drying

Convective method of drying is used to remove water from banana through heat transfer in modern drying. Hot air is allowed to pass through the banana products in a manner to transfer the heat to the banana, and moisture is removed effectively [58].

Combination of osmotic and convective drying methods have been studied on many fruits and vegetables such as mango [59], mushrooms [60], ginger [61], jackfruit [62], button mushroom [63] and grapes [64], and these methods could be applied to drying of banana.

2.2.2 Drying by radiation

It has been discovered and reported that long drying time and high temperature are the factors responsible for the loss of heat-sensitive components of banana in traditional convective hot air drying. Drying by radiation is an alternative method that could be used to overcome the problems encountered in hot air drying. The use of electromagnetic radiation as in the case of microwave radiation is achieved through space by means of electric and magnetic fields. Microwave heating requires lesser amounts of time and temperature to remove moisture from banana slices [65]. One of the problems of microwave heating is due to low availability of water towards the end of the drying process. Radiation through microwave could be combined with other methods of drying such as vacuum drying which is an advantage over other methods [65]. Drying by radiation has been used to dry various agricultural produce including banana [66–68].

2.2.3 Freeze-drying

Freeze-drying uses the principles of moisture sublimation to remove from produce. Falade and Igbeka [69] have reported that the non-availability of liquid water during freezing and low temperature results in the production of a superior quality end product and most of the reactions involving the microbes are completely stopped. Freeze-drying method has several advantages over other drying methods in that its products have better rehydration property due to rapid drying and the organoleptic property of the rehydrated banana is almost the same with the fresh product [69]. Other benefits of freeze-drying method are as follows: freeze-dried products have minimum volume reduction, minute chemical change and minimum loss of volatile components [70]. However, freeze-drying is very expensive and uses more energy. Because of longer freeze-drying time, the product may collapse during drying which could lead to loss of aroma [71].

2.2.4 Osmotic drying

Osmotic drying involves the use of hypertonic solution; banana slices are placed in a hypertonic solution which causes a difference in concentration gradient and removal of water from banana to the solution. There is also diffusion of the solutes from the solution into the tissue of the banana slices [72]. The mass transfer which occurs during osmosis could be responsible for the change in physical, chemical and nutritional values, taste and structural properties of the final products [62, 69, 73]. Osmotic active solutes include monosaccharides, disaccharides and salts such as sodium chloride. The major advantage of the process is that it could be conducted at room temperature since energy required for carrying out the procedure is significantly less [74].

2.2.5 Hurdle technology

Hurdle technology is a method of ensuring that pathogens in banana fruits can be eliminated or controlled through the use of hurdles. This means the banana fruits will be safe for consumption and their shelf life will be extended. Hurdle technology usually works by combining several approaches thought of as 'hurdles' which the pathogen has to overcome if it is to remain active in banana flour. The right combination of hurdles can ensure that all pathogens are eliminated or rendered harmless in the final products [75].

Leistner [77] defined hurdle technology as a planned application and combination of hurdles which eliminates or reduces the microbial load and makes dried banana safe and stable as well as improves or maintains the organoleptic and nutritional quality and the economic viability of dried banana. The organoleptic quality of the banana products refers to its sensory properties, which includes look, taste, smell and texture.

Several combinations of hurdles are used in banana preservation. Examples of hurdles in a banana fruit system are high temperature during processing; low temperature during storage, increasing the acidity and lowering the water activity or redox potential; or the presence of preservatives. Alasalvar [76] reported that bananas are preserved according to the type of pathogens and how risky they are. The author reinstated that the intensity of the hurdles can be adjusted individually to meet consumer preferences in an economical way, without compromising the safety of the products.

Several hurdles are considered to be important in the preservation of various vegetables and fruits including banana to enhance their stability and shelf life. Shelf-stable grated carrot products are developed using hurdle technology.

2.3 Drying kinetics and modelling

The *drying kinetics* is used to describe the combined macroscopic and microscopic mechanisms of heat and mass transfer during *drying*, and it is affected by *drying* conditions, types of *dryer* and characteristics of materials to be *dried*. Studying drying kinetics is a means to choose appropriate drying methods and to control the processes of drying. It is also important for engineering and process optimization. Drying kinetics is used to show removal of moisture from products, and it has to do with process variables, and hence, a better understanding of drying rate will help in developing a drying rate model [78]. There are three drying models, namely, theoretical, semi-theoretical and empirical according to Khazae and Daneshmandi [79]. Theoretical models dealt with internal resistance in transfer of moisture, while semi-theoretical and empirical models worked on external resistance in the transfer of moisture between air and products [80]. Empirical model's main shortcoming is that it does not consider the basics of drying process but explains only the drying curve for drying conditions but not the processes that occur during drying [81]. Examples of semi-theoretical models are the Lewis model, Henderson and Pabis model, Logarithmic model, Page model, etc.

The theoretical model that is commonly used in drying rate is Fick's second law of diffusion. Theoretical models have been found to be inadequate, tend to generate erroneous results and are complex for practical applications. Therefore, in food drying semi-theoretical models have been developed as a better model to fit the drying data of banana fruits to be dried [82]. In the case of the Henderson and Pabis model, it was first used for model drying of corn. But due to inaccuracy and high degree of temperature difference between kernel and air, the model could not be fitted during the first 1 or 2 h of drying banana [83]. The Lewis model is a special case of the Henderson and Pabis model [84]. However, the model has been found to be inaccurate because it overestimates the first period and underestimates the last period of drying. But, semi-theoretical models have been found to be the simplified general series solutions of Fick's second law (**Table 2**).

2.3.1 Effect of air temperature and air velocity on drying kinetics

In drying kinetics, air temperature is one of the major factors influencing the drying kinetics during dehydration. Krokida et al. [83] reported that the drying constant, equilibrium moisture content and moisture diffusivity increase as the temperature increases. Tzempelikos et al. [85] in their experiment on the time of drying banana fruits found that the drying was influenced by the air temperatures and air velocities used for drying. They discovered that drying time was reduced by 30% with increase in the air velocity at a temperature of 60°C, while 54% reduction in drying time was observed when temperature was increased from 40 to 60°C at an air velocity of 2 m/s.

2.3.2 Effect of shape on drying kinetics

Borges et al. [86] studied the influence of shape on the drying kinetics of banana. They reported that the shape of produce has positive influence drying kinetics and that the drying rate was significantly higher with disk-shaped Dagua banana as compared to the cylindrical shaped banana. They also reported that shape of produce has positive influence on drying temperature of Parta banana and observed that the effect of blanching in Parta banana could been seen when dried at 40°C as compared to shape; the air velocity and air temperature were found to have a more profound effect on the drying time. They also observed that the drying square slices were lower than the cylindrical samples.

Models for drying	**Formulas**	**Reference**
Two term	$MR = a\exp(-k_0 t) + b\exp(-k_1 t)$	[81]
Simplified Fick's diffusion equation	$MR = a\exp[-c(t/L^2)]$	[82]
Henderson and Pabis	$MR = a\exp(-kt)$	[83]
Modified page II	$MR = \exp(\exp(-c(t/L^2)n)$	[60]
Lewis model	$MR = \exp(-kt)$	[85]
Simplified Fick's diffusion	$MR = a\exp(-c(t/L^2))$	[60]
Page model	$MR = \exp(-kt^{n)}$	[62]
Modified page	$MR = \exp[-(kt)^n]$	[63]

Key terms: T—drying time (s); a, b, c, g, n—dimensionless constants for drying; k, k_1, k_o—drying velocity constants; exp—exponential; MR—moisture ratio; L—thickness of the material; R—correlation coefficient.

Table 2.
Mathematical models used in banana drying kinetics.

2.3.3 Effect of pretreatment

Pretreatment is done in banana slices before drying has been found to reduce the drying time, to improve taste and structure, to preserve flavour and to maintain the nutrition of banana. Pretreatment reduces the initial moisture content and modifies the tissues of the banana fruits which help to accelerate the drying rate [87].

Common pretreatments applied to fruits prior to drying operation include blanching, lemon juice, ascorbic acid, sulfuring, honey dip, salt solution and osmotic pretreatment, ethyloleate, NaOH, olive oil, skin puncturing and K_2CO_3 [88–91, 92]. Studies have shown that pretreating with an acidic solution or sodium metabisulfite dip also enhances the destruction of potentially harmful bacteria during drying, including *Escherichia coli* O157:H7, *Salmonella* spp. and *Listeria monocytogenes* [92].

2.3.4 Effect of relative humidity

Relative humidity has serious effect on drying rate and drying kinetic of banana fruits. Misha et al. [93] worked on the effect of humidity and temperature in the drying kinetics. They used drying temperature (45, 50 and 55°C) and relative humidity (10, 20 and 30%) variations at an air velocity of 1.0 m/s. They found that two-term model described the drying kinetics more accurately and then the rest of the models used in the experiment. They also found that the drying time was reduced as the temperature increased at constant air humidity. They observed that relative humidity of the air had an insignificant effect on the drying curve; this was attributed to the initial moisture content of the sample.

2.3.5 Mass transfer parameters

Drying process is used to prolong the storage or shelf life of banana products without changing the quality, structure and chemical properties. This is critically needed for quality of banana products and availability. The efficient and effective drying process could be obtained through an effective use of time, energy and cost [94]. This could also be seen in through speed and timely removal of moisture during the drying process. It has been established that moisture removal depends on the drying method and this will affect the technique of moisture movement towards evaporation for the drying process. Moisture movement is also effective moisture diffusivity and activation energy dependence [94].

2.3.6 Effective moisture diffusivity

Effective moisture diffusivity is defined as movement of moisture in banana products and is drying rate related [94, 95]. The difference between effective moisture diffusivity and drying rate is that effective moisture diffusivity is related to moisture velocity within the material, while the drying rate is the moisture vapourizing rate to air and depends directly on the pressure gradient that exists between material and the air due to a temperature gradient [94]. Effective moisture diffusivity is the parameter used to determine the drying rate of banana products and an indicator to determine an appropriate drying method that could be used to extend the banana product shelf life.

Also, according to Omolola et al. [87], effective moisture diffusivity is said to be a function of material moisture content and temperature, as well as of the material structure [91]. Omolola et al. [87] in their work reported that the values of moisture diffusivities increased with increasing oven temperature. Similar observation was made by Aghbashlo et al. [95], Caglar et al. [96] and Doymaz and Ismail [97]. Omolola et al. [87] also reported that the disparities in moisture diffusivity values obtained in their study and the values reported for banana by Marinos-Kouris and Maroulis [98] and Thuwapanichayanan et al. [99] may be attributed to the effect of variety, geographical location, composition and tissue characteristics of the bananas.

2.3.7 Activation energy

Activation energy is energy needed to severe the moisture particles bonding for moisture movement in banana drying [94, 95]. Relationship between effective moisture diffusivity and activation energy is associated with drying characteristics and the effect of drying conditions on effective moisture diffusivity and activation energy of products [95, 100–102]. According to Xiao et al. [103], the activation energy, for a typical drying operation, ranges from 12.7 to 110 kJ/mol. Doymaz [104] reported the activation energy for drying banana slices to be 32.65 kJ/mol.

In determining activation energy, the Arrhenius equation is used in a modified form to illustrate the relationship between moisture diffusivity, mass transfer coefficient and ratio of drying process output power density to sample amount or the temperature for the calculation of the activation energy on the drying process [105, 106].

$$D_m = D_0 \exp\left(\frac{E_{ad} m_0}{P}\right) \tag{1}$$

$$H_{m\text{-}av} = h_0 \exp\left(\frac{-E_m m_0}{P}\right) \tag{2}$$

2.4 Quality aspects of dehydrated banana flour

2.4.1 Rehydration ratio

Rehydration of banana slices depends on processing conditions, sample preparation, sample composition and extent of the structural and chemical disruption induced by drying [107]. Singh and Pandey [107] reported that the duration and severity of the drying process with the speed and degree of rehydration reflect faster and complete rehydration with decreased drying time. They opined that a minimization of shrinkage and the presence of well-defined intercellular voids show to promote increased rehydrating rate. Dried banana slices could be rehydrated at 25°C for 2 h by being immersed in 60 mL of distilled water. The rehydration ratio is described by:

$$Rr = \frac{m_1 - m_d}{m_1} \tag{3}$$

2.4.2 Color measurement

Color is a vital quality characteristic in dehydrated banana to nearly every consumer. It serves as an indicator of the intrinsic good qualities [108]. The relationship of color with consumer acceptability is common and inevitable [108]. It has been reported that drying operation changes the surface characteristics of foods and hence alters their reflectivity and color [109]. The color of food products is a very important quality parameter. L (lightness), a (redness) and b (yellowness) color values of the fresh and dehydrated banana slices can be measured using a spectral photometer or a colorimeter before and after drying.

Total color change and hue angle could be calculated as follows:

$$\Delta E = \left(\left(L^*{}_d - L^*{}_f\right)^2 + \left(a^*{}_d - a^*{}_f\right)^2 + \left(b^*{}_d - b^*{}_f\right)^2\right)^{1/2} \tag{4}$$

$$H = \tan^{-1}(b/a) \tag{5}$$

2.4.3 Bulk density and shrinkage

The bulk density is the ratio of the mass of banana slices to its total volume, and it can be determined by filling the slices in a cylinder of known volume and then weighing with a balance [110].

$$\rho_b = m/V \tag{6}$$

Shrinkage is an important change in the physical state of the product during drying which affects the quality of the final material, producing large alterations in its volume. Shrinkage can be expressed as ratio between the initial volume and the volume at a certain time after the moisture loss processes. Ramos et al. [111] reported shrinkage is the reduction of the product size which is a result of the reduction of its cellular dimensions of the product due to loss of moisture. According to Aguilera [112], shrinkage which occurs as a result agricultural produce drying is due to viscoelastic matrix contraction into the space previously filled by the water removed from the cells during dehydration.

Shrinkage of bulk banana slices could be represented by:

$$\mathrm{Sh} = \left(V^d/V_0\right) \tag{7}$$

2.4.4 Consumer perceptions/concerns and expectations about innovative and emerging banana processing technologies

Consumers around the world are better informed and educated as well as more demanding in their purchase preferences for quality health-promoting banana products. The banana industry has continued to search for innovative and novel technologies to provide safe, quality and stable banana products for human consumption. However, nonthermal processing technologies offer unprecedented opportunities and challenges for the banana industry to produce and market safe, high-quality health-promoting banana products. The research and development of nonthermal processing technologies for banana processing will provide an excellent balance between safety and minimal processing, as well as provide a balance between economic and quality requirements of the banana products [113]. Nonthermal banana processing is believed to be a new alternative to thermal banana processing.

Currently, there are many nonthermal banana processing and preservation opportunities and challenges that need further research by the food industry. The advocates of nonthermal technologies rest their argument not only in the inactivation of microorganisms and enzymes but also in improving yield and development of foods with novel quality and nutritional characteristics [114, 116, 118]. Nonthermal processing could be effectively combined with thermal processing to provide improved banana safety and quality. Nonthermal processing has been found to facilitate the development of innovative banana products. Nonthermal technologies have been used to decontaminate, pasteurize and produce commercial sterilization of some banana products with good quality and excellent nutrient retention. The most important priority for future food science research will be the demand by consumers for technologies to meet consumer expectations with optimum-quality safe-processed banana. Zhang et al. [113] listed priorities and factors to consider when conducting research into novel nonthermal and thermal technologies for quality safe banana products as target microorganisms to provide safety, target enzymes to extend quality shelf life, maximization of potential synergistic effects, alteration of quality attributes, engineering aspects, reliability and economics of technologies and consumer perception of banana products from these technologies. They are of the opinion that the new technologies 'to process foods should be driven at maximizing safety, quality, convenience, costs, and consumer wellness' [115, 117–119].

2.4.5 Glass transition on shrinkage in convective drying

Several methods are employed for the preservation of banana products; drying is one of them. Drying is a heat and mass transfer process which removes moisture and thereby reduces the water activity of the banana products through vapourization or sublimation, which minimize enzymatic and microbiological reactions within the banana products. Several researchers have worked on drying and drying rate of different food materials. The drying rate has been found to depend on factors that influence the transfer mechanisms, such as the vapour pressure of the material and of the drying air, the temperature and air velocity, water diffusion in the material, the thickness and surface exposed for drying [120, 121].

Shrinkage of dried banana products is an important change in the physical state of the product during drying which affects the quality of the final material, producing large alterations in its volume. This phenomenon during drying is affected by glass transition. According to Roos [121], glass transition temperature (Tg) is the temperature at which an amorphous system changes from the glassy to the rubbery state. According to him in the glassy state, molecular mobility is extremely slow, due to the high viscosity of the matrix. Thus, the Tg can be taken as a reference parameter to characterize properties, quality, stability and safety of dried banana products [122].

Mayor and Sereno [123] and Bhandari and Howes [124] found that at most drying conditions, a significant amount of the dried product remains in the amorphous state, mainly due to insufficient time for crystallization to occur at the given drying condition. They observed that at rubbery state, shrinkage almost entirely compensates for moisture loss and changes in material volume are equal to the volume of removed water. However, it was observed that in food systems, shrinkage is rarely negligible, and it is advisable to take it into account when predicting moisture content profiles in the material undergoing dehydration [125–127].

2.4.6 Optimization of drying conditions of bananas in tray dryer using response surface methodology

Drying of banana products involves mass transfer phenomenon. Volume reduction or shrinkage occurs simultaneously during drying process, and it is an undesirable phenomenon in dried products. In general, reduction in volume is due to moisture transfer from dried banana products. This could be as a result of heat transfer into banana slices and mass transfer from the inside to the surroundings thereby causing unfavourable changes in dimensions and shape of the dried products [128, 129].

Response surface methodology (RSM) is a collection of statistical and mathematical techniques that has been successfully used for developing, improving and optimizing processes [129]. RSM enables a reduction in the number of experimental trials needed to evaluate multiple parameters and their interactions, thus requiring less time and labour. RSM has been widely applied for optimizing processes in the food industry [128–130]. It is used for product quality improvement in the drying process and has been widely used in new product development, as well as in the improvement of existing product design [130, 131]. There are already a number of studies on RSM applications in optimization of food processes that include optimization of banana production, processing parameter optimization for obtaining dry banana with reduced cooking time [132–134].

3. Conclusions

This chapter showed that moisture content of banana fruits at harvest time is too high for storage and needs to be reduced. Drying characteristics, quality and mass transfer parameters for drying of banana slices were explained, and the process was discussed. It has been found that higher values of effective moisture diffusivity will accelerate moisture velocity within banana slices to achieve removal of moisture from produce for equilibrium moisture content at specific relative humidity. This will help in designing an effective drying method that will save time and energy consumption as well as cost to get good quality products. It was explained that Suzuki's model could be used to explain shrinkage during hot air drying process for banana slices. Shrinkage is a phenomenon and a significant alteration to be considered on quality of dried banana in food engineering applications. The use of this approach will be valuable to select proper drying conditions in order to obtain good quality dried banana products.

Conflict of interest

There is no any conflict of interest.

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Chapter 6

Integrating Text Mining and Network Analysis for Topic Detection from Published Articles on Banana Sensory Characteristics

Victoria Jideani

Abstract

Published articles (28) from PubMed database on banana sensory characteristics were from 2002 to 2018. They were mined to detect the topic of discussion using the KNIME software. The texts were tagged with the Open Source Chemistry Analysis Routines (OSCAR) chemical named entity and preprocessed by filtering and stemming, thereafter the topic of discussion detected with the Latent Dirichlet Allocation and term co-occurrence was determined using KNIME data mining software. The co-occurrence terms were converted to node adjacency matrix and imported into Gephi Graph Visualisation and Manipulation software version 0.02. Network statistics such as modularity class, degree centrality, betweenness and closeness centrality were estimated. Majority of the OSCAR tagged words (50.8%) were chemical compounds and 47.3% ontology terms. The directed network consisted of 53 nodes and 904 edges. There were four modularity classes. The terms with high betweenness centrality (>45) were, accept, fruit, analysis, coat, food, composite and banana. Three topics were detected from the documents, namely (1) quality of banana fruit and peel; (2) use of banana fruit in food and wine and (3) sensory acceptability of banana peel and flour in food products. This chapter provides details each topic.

Keywords: banana, sensory, text mining, network analysis, topic detection, KNIME, OSCAR, peel, flour, wine, betweenness

1. Introduction

Banana (*Musa* spp.) is one of the most produced and consumed fruit globally comprising of an edible pulp and a peel [1, 2]. Majority of the banana in the world was produced in Asia (52.8%), America (26.6%), Africa (17.8%), Oceania (1.4%) and Europe (0.4%) between 2000 and 2016. Green banana flour (GBF) from the pulp is rich in vitamin C and A, glutathione, flavonoids and phenolic compounds with potent antioxidant activity [3]. Banana peels are rich in phenolics and are good source of antioxidants [1]. Banana peel and unripe banana fruit are rich in dietary fibre and indigestible carbohydrates, proteins, essential amino acids, cellulose, hemicellulose, lignin, starch, resistant starch, polyunsaturated fatty acids and potassium [4]. The interest in GBF relates to its high resistant starch (40.9–58.5%) and dietary fibre (6.0–15.5%) as well as bioactive compounds [4]. The high resistant starch might contribute to controlling glycemic indexes, cholesterol, gastric fullness, intestinal regularity and fermentation by intestinal bacteria, producing short-chain fatty acids that can prevent cancer in intestinal cells [5]. The health benefits of banana have attracted production of innovative food products in addition to their sensory properties in recent years. These scientific results have been communicated in the form of scientific papers containing unstructured data which use free flowing natural language combined with domain-specific terminology and numeric phrases [6]. Manual abstraction of information from these papers for literature review has huge labour cost and delay with considerable source of error and data corruption. Hence, scientific papers are attractive for the development of machine processes for automatic information extraction [6] using text mining.

Text mining uses the Natural Language Processing (NLP) tools for the automatic discovery of previously unknown information from unstructured data [7, 6] typically consisting of four stages (a) information retrieval by gathering a set of textual materials for a given topic; (b) entity recognition characterised by identifying textual features from gathered texts; (c) information extraction which aims to extract relationships among the recognised textural features such as occurrence and co-occurrence of specific terms (indexing) and (d) knowledge discovery, the extracted relationships are used to identify useful patterns from the data set [8]. Network analysis is a sociology techniques used to study the relationships and community structures in social data and has since been applied in other fields such as bioinformatics in order to find key molecular markers and communities within an interaction network [8]. It can be used to study the co-occurrence of specific terms.

Konstanz Information Miner (KNIME) text processing feature can read and process textual data and transform it into numerical data (document and term vectors) such as the term co-occurrence adjacency matrix in order to apply regular KNIME data mining nodes [9].

The objective is to process the unstructured textural information related to banana sensory using text mining and network analysis approach in order to extract knowledge like the use of banana in innovative food products and visualise associated relationship to the banana sensory attributes and consumer acceptability.

2. Topic detection and network analysis methodology

Published articles (106) from PubMed database on 'banana sensory' were uploaded into KNIME (Konstanz Information Miner) software using the PubMed document parser. Some of the articles were observed not to relate to the manuscript of interest. Hence, the documents were indexed for 'banana' in the titles using the table indexer and index query nodes resulting to 28 relevant documents. The texts were tagged with the OSCAR (Open Source Chemistry Analysis Routines, an open source extensible system for the automated annotation of chemistry in scientific articles) chemical named entity using the Oscar Tagger node and pre-processed by filtering and stemming, then transformed into a bag of words, which was filtered again such that only the terms with relative frequency from 0.02 to 1.0 was used as features (**Figure 1a**). The term co-occurrence counter node was used to count the number of co-occurrences in sentences. Following which the documents were transformed into

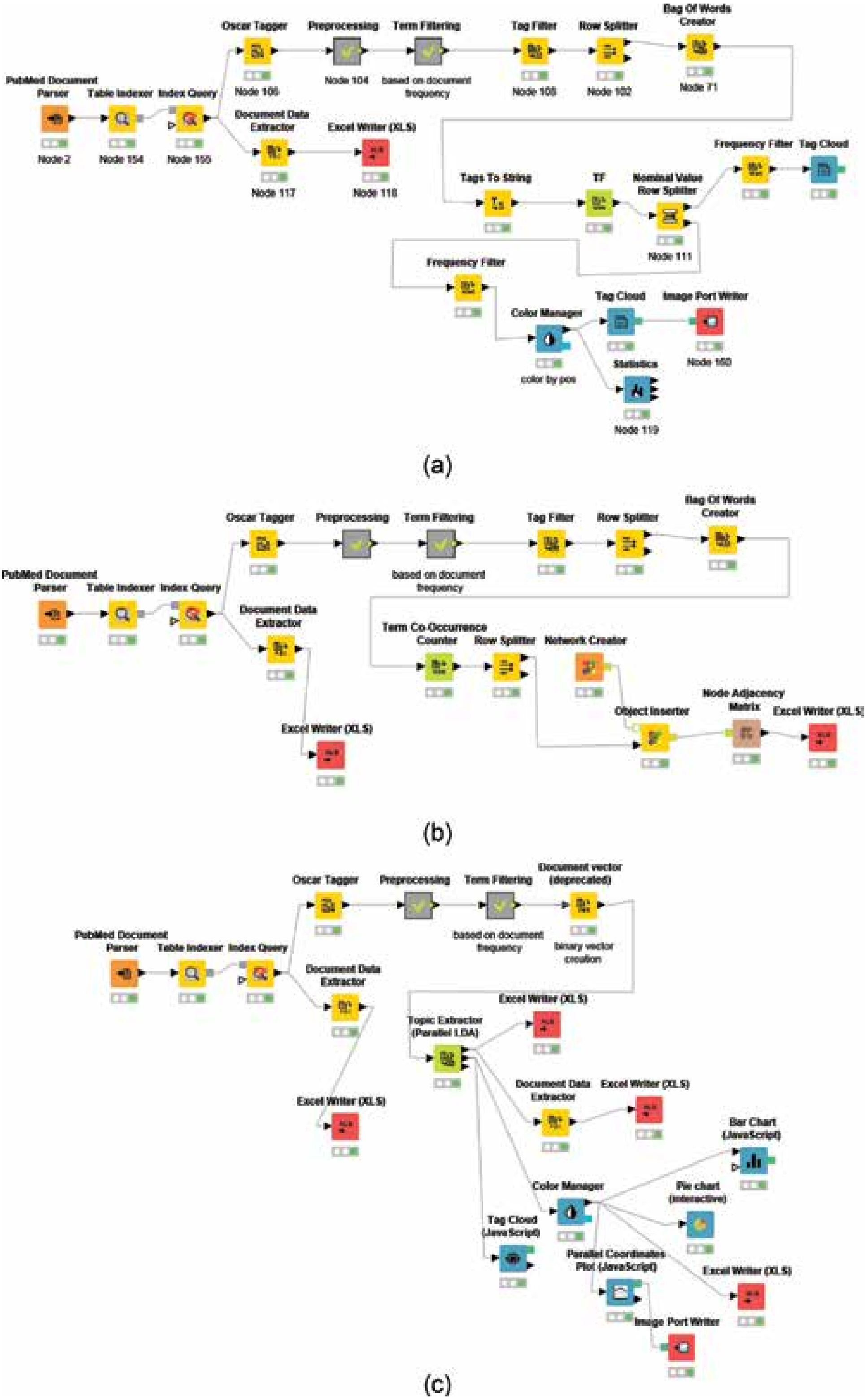

Figure 1.
KNIME network for banana sensory data mining: (a) OSCAR tagging, (b) term co-occurrence and (c) knowledge detection.

document vectors. The co-occurrence terms in at least four sentences were converted to node adjacency matrix (**Figure 1b**) and imported into Gephi Graph Visualisation and Manipulation software version 0.02. Network statistics such as modularity class, degree centrality, betweenness and closeness centrality were estimated. Degree centrality is the central tendency of each node in the network. The more direct connects each term has, the more power it has in the network and so the more important it is. The betweenness centrality reflects the ability of a node to take control of other nodes communication and control resources in the network. Closeness centrality is the ability of a node not being controlled by other nodes and measures the closeness of a node to others in the network. The Latent Dirichlet Allocation (LDA) node which uses a machine learning for language toolkit (MALLET) topic modeling library was applied to extract relevant information from an unstructured text (**Figure 1c**).

3. Author network

The author network (**Figure 2**) is characterised by 113 nodes (researchers) and 217 edges indicating connectedness among the researchers. Although there are five groups in the author network, the groups are not well connected with network density of 3.4%.

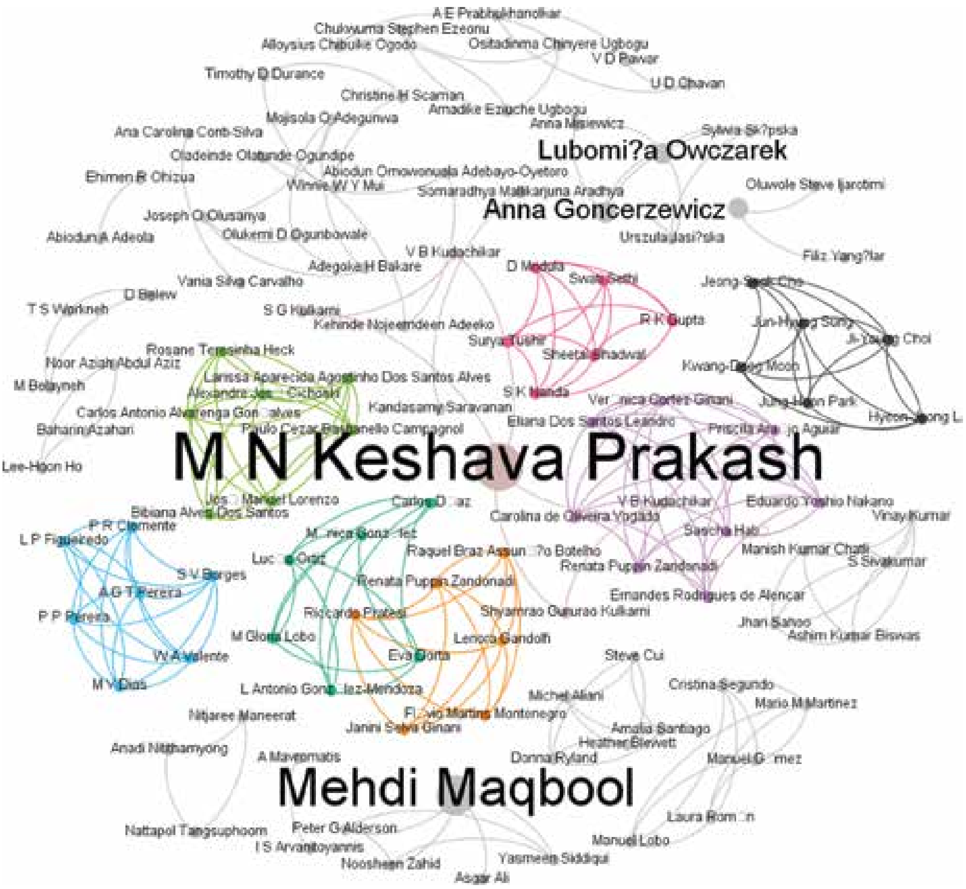

Figure 2.
Author network of banana sensory documents.

4. Chemical entities used in banana sensory documents

The chemical entities [1462] identified using the Open Source Chemistry Analysis Routines (OSCAR) tagger node include chemical compound (CM) [50.8%], Ontology (ONT) [47.4%], reaction name (RN) [1.2%] and chemical adjective (CJ) [0.7%] as detailed in **Figure 3**.

Chemical compounds related to banana sensory include modified atmospheric packaging (MAP), beta-glucan, green banana flour (GBF), carbon dioxide, alpha-amylase and ethylene. Reaction name include dehydration. The flour from the peels and banana pulp requires dehydration to remove the moisture. Ontology is a set of concepts and categories in a subject area and includes food, nutrients, protein, process, pectin, antioxidants and ascorbic acid.

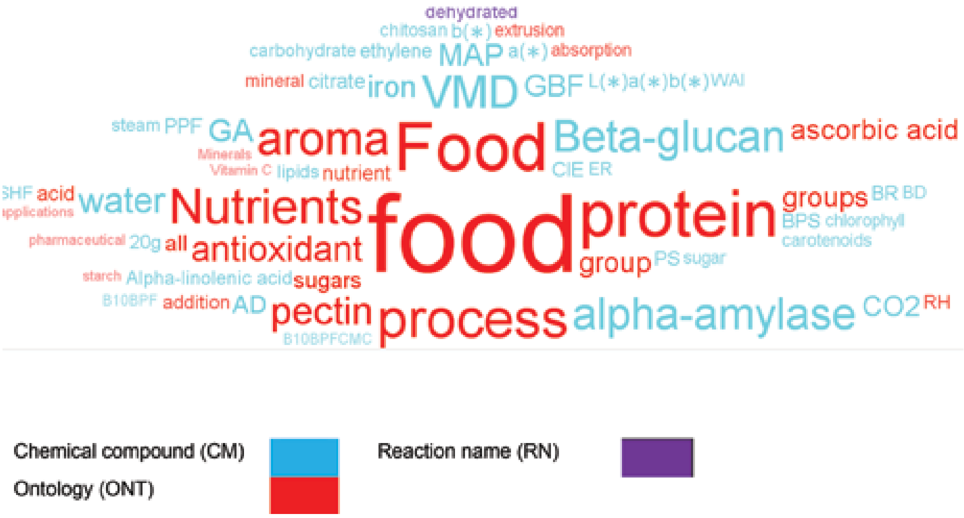

Figure 3.
Chemical entities associated with banana sensory documents.

5. Co-occurrence term interaction in the banana sensory documents

The directed network for the co-occurrence terms consists of 53 nodes and 904 edges with in-degree ranging from 6 to 37 (banana) with a mean of 17. At least 50% of the nodes are co-occurring with 17 other nodes. Nodes with many ties like banana in this instance are said to be prominent, or have high prestige as many nodes seek to direct ties towards them, an indication of importance. The in-degree is a measure of popularity based on the number of connections to a node [10], representing the amount of attention the node receives. Hence, banana co-occurred more than other terms. This is expected as the topic of interest is on banana.
The out-degree ranged from 0 to 44 (accept) with a mean of 17. Nodes with high out-degree like accept in this instance can influence others and are often said to be influential. The high out-degree is expected since sensory evaluation is related to acceptability characteristic of a product. The topic of interest being sensory attributes of banana and its products. The limitation of using a node's degree to quantify its significance is that each connection is valued equally as it assumes that forming a connection with an important node counts as much as a connection to an unimportant one [10]. Practically, developing a connection with the chief executive

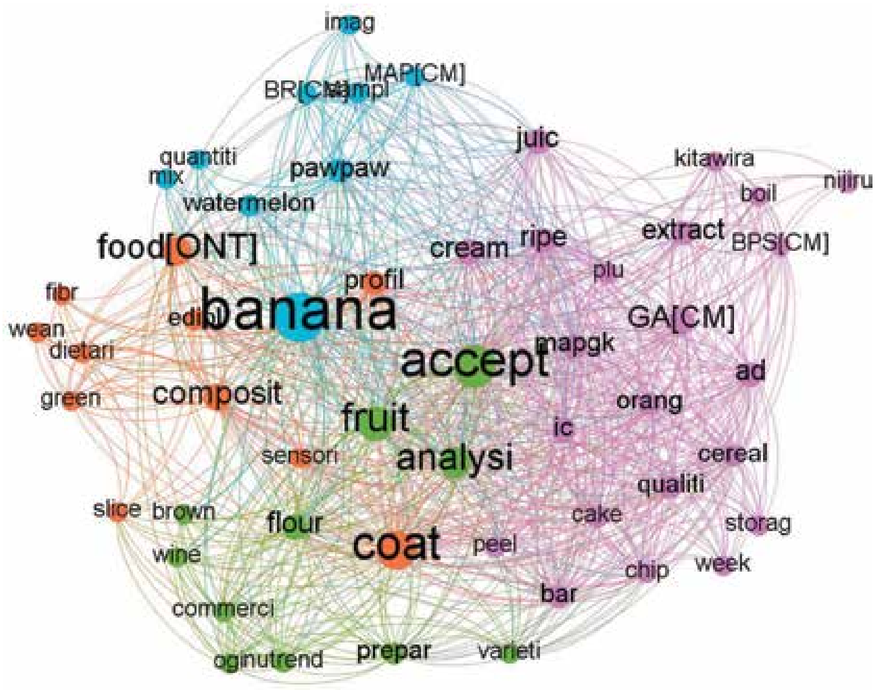

Figure 4.
Force atlas 2 layout based on modularity class, the class 0 consisting of 20.7% (green), class 1, 20.8% (red), class 2, 41.5% (purple) and class 3, 17.0% (blue) of the nodes. Node size based on betweenness centrality (min size = 20; max size = 100).

of a company gives more influence than a connection with someone in an entry level position.

The connectedness of the nodes is detailed in **Figure 4**. The nodes were coloured based on the four modularity classes. The base class consisting of 20.7% (green), class 1, 20.8% (red), class 2, 41.5% (purple) and class 3, 17.0% (blue) of the nodes. Betweenness centrality accounts for the nodes that lie on many short paths having considerable control over information diffusion in the network acting as gatekeepers of information [10]. Terms with high betweenness centrality are also high in in-degree and eigenvector centrality and are therefore connected to many highly connected terms. The betweenness centrality ranged from 0 to 192. The terms with high betweenness centrality (>50) were accept (139), fruit (92), analysis (74) [class 0]; coat (125), food (60) [class 1] and banana (192) [class 3]. These terms are important in conveying the information on banana sensory profile. Hence, banana sensory relates to its use in mixed fruits, image analysis, gum Arabic and chitosan coated banana, and co-extruded with food grains.

6. Discovered knowledge on banana sensory

Three topics each consisting of five terms were extracted from the banana sensory documents as detailed in **Figure 5**. Topic 0 contributing 27.98% correlates to quality of banana fruit and peel. Topic 1 (23.21%) correlates to the use of banana fruit in food and wine. Topics 2 (48.81%) relates to sensory acceptability of banana peel and flour in food products. The details of each topic will be provided.

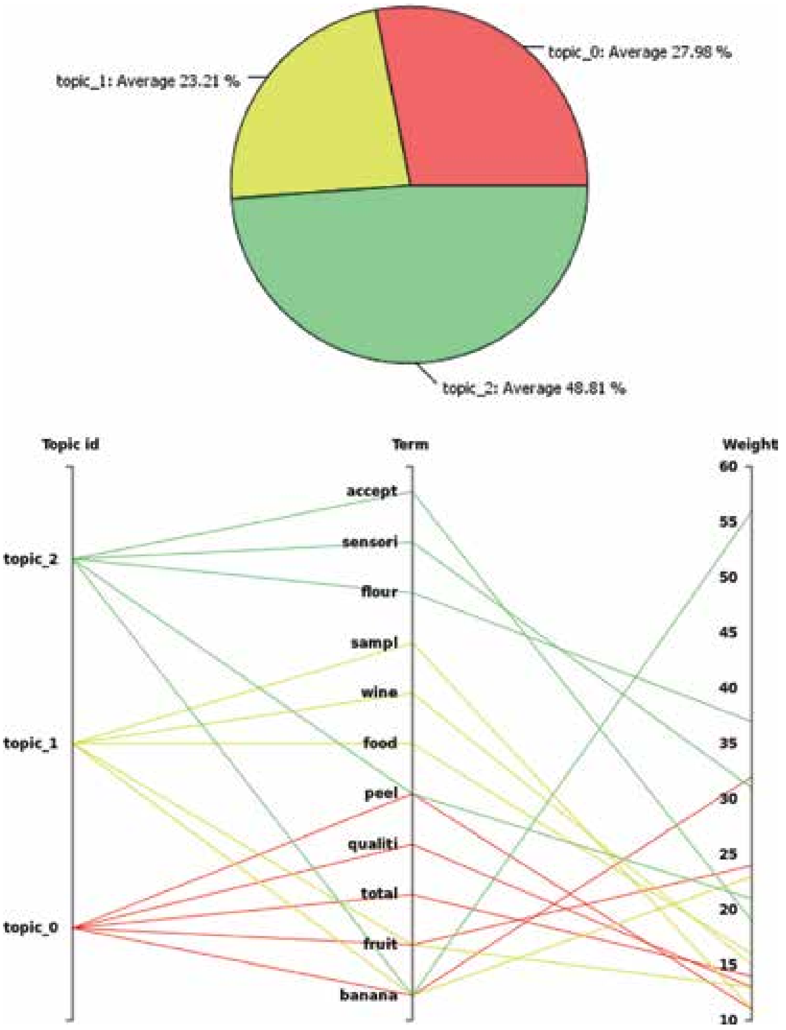

Figure 5.
Detected topics from the banana sensory documents in PubMed from 2002 to 2018.

7. Quality of banana peel and fruit

Kudachikar et al. [11] reported that packing optimally matured (75–80%) ‘Robusta’ banana in modified atmospheric packaging with low density polyethylene (LDPE) films alone and in combination with green keeper as ‘ethylene absorbent’ under low temperature (12 ± 1°C, 85–90% RH) extended the shelf life up to 5 and 7 weeks, respectively, compared to 3 weeks in openly kept control fruits stored under similar conditions. The green keeper treated samples contained three sachets containing $KMnO_4$ (10 g/sachet) as ethylene absorbent placed in each LDPE film. Sensory quality of the fully ripe fruits 5 days after the ethrel dip was very good. Banana fruits treated with 500 ppm of ethrel ripened evenly in 6 days at 20 ± 1°C with excellent external colour, taste, flavour and overall quality [12]. Using image analysis it was reported that banana peel browning occurred faster in banana packaged in CO_2 gas exchange packaging [13].

Banana fruits coated with a mixture of 10% gum Arabic and 1% chitosan maintained delayed colour development, reduced the rate of respiration and ethylene production during storage and maintained the overall sensory of the fruits for 33 days [14]. The authors concluded that 10% gum Arabic with 1% chitosan could be used as an edible coating to commercially extend the storage of banana fruits for up to 33 days. Belayneh et al. [15] studied the physicochemical properties of four Ethiopian cooking varieties (Cardaba, Nijiru, Matoke and Kitawira). Cardaba variety had high fruit weight, fruit length, fruit girth, fruit volume, total soluble solids, ascorbic acid, dry matter and low titratable acidity and provides the best quality boiled pulp. Nijiru, Kitawira and Matoke were superior in acceptable quality chips and are recommended for chips by food processors in Ethiopia. Cardaba varieties were heaviest and the longest containing 88% more edible portions per unit fresh weight than the peel, whereas Kitawira and Nijiru are the smallest, shortest and thinnest fruit.

Sulphur fumigated fully ripe banana slices (8 mm thickness) soaked in 60° brix sugar syrup containing 0.1% potassium metabisulphite + 0.1% citrate + 0.2% ascorbic acid (at 2 g/kg slices for 2 h) had acceptable colour, appearance, flavour, texture, taste and overall acceptability with non-stickiness [16].

The improvement in the storage of banana for 33 days with edible Arabic gum and chitosan coating will greatly reduce wastage. Reduction in banana pulp browning will contribute to consumer appeal of banana products.

8. Use of banana fruit in food and wine

Mridula et al. [17] developed food grains (maize, defatted soy flour, sesame seed)-banana based nutritious expanded snacks using extrusion cooking. Banana pulp positively correlated with water solubility index, total minerals and iron content but negatively correlated with water absorption index, protein and overall acceptability. Optimised product was obtained by blending the coarsely ground maize (78.5), sesame seeds (7.5%), defatted soy flour (14%) with 8 g ripe banana pulp, 350 rpm screw speed and 14% feed moisture with 15.5% protein, 401 kcal/100 g, 4.48 mg/100 g and 7 overall sensory acceptability on a 9-point hedonic scale. Higher levels of the ripe banana pulp in the feed formulation resulted to increased Maillard reaction leading to high redness in the final product. The protein and calories of the snack could contribute about 50% of protein and 20% of calorie requirement of a 7–9-year-old child; hence it has the potential in combating protein-calorie malnutrition [17].

Vacuum-microwaved banana chips with 10% moisture had more crispiness, significantly higher volatiles and greater sensory rating than the air dried with similar moisture content [18]. Wheat pasta was produced with whole-wheat flour (60.6%) and whole egg (39.4%). The green banana pasta was produced with green banana flour (40.0%), egg whites (31.5%), water (16.4%), guar gum (2.4%) and xanthan gum (2.5%). The rationale for the use of egg white was its strong influence on the quality of gluten-free pasta products due to its high protein content that can be coagulated at low heat, easy access and low cost [5]. The hydrocolloids were included to augment the action of the egg white. However, the authors did not check whether the interaction between guar gum and xanthan is additive, synergistic or antagonistic. The pasting properties of Bambara groundnut flour with carboxylmethyl cellulose, starch and xanthan to obtain a non-gluten flour revealed that the xanthan had no significant effect on the pasting properties [19, 20]. Thus using xanthan in such a system increases the cost with no functional merit. Green banana pasta containing approximately 98% less lipids showed greater acceptance (84.5% with celiac and 61.2% with non-celiac) than wheat pasta (53.6% with non-celiac individuals). The consumers did not identify any significant difference between the wheat and the green banana pasta in appearance, aroma, flavour and overall quality [5].

Ogodo et al. [21] reported mixed fruit (pawpaw, banana and watermelon) wine using *Saccharomyces cerevisiae* isolated from palm wine. The acceptability of the wines was rated as pawpaw and banana > pawpaw and watermelon > pawpaw, watermelon and banana > banana and watermelon wine. These studies highlight the potential of banana pulp in extruded, fried food products and wine.

9. Sensory acceptability of banana peel and flour in food products

Ripe banana pulp is rich in fibre, polyphenols and simple sugars (61.1 g/100 g) making it ideal for sucrose replacement in baked products. However, in cake formulation inclusion of ripe banana flour slightly lowered the specific volume and increased hardness [22]. Consequently, a decline in sensory acceptability. Nevertheless, the added banana flour significantly improved the nutritional properties of the cakes with increase in dietary fibre, polyphenols and up to three-fold improvement in antioxidant capacity.

Arvanitoyannis and Mavromatis [23] reported that the physicochemical (pH, texture, vitamin C, ash, fat, mineral and sensory properties of banana are related to the genotype and growing conditions with the minerals accurately discriminating banana cultivars of different geographical origin. The beneficial properties of banana relate to its high dietary fibre and antioxidant compounds, the latter being abundant in the peel. Extracts from banana peel was used as an antioxidant in freshly squeezed orange juices and juices from concentrate [24]. Adding the extract to both types of orange juice increased the free radical scavenging capacity as well as increase in antioxidant capacity using 2,2′-azino-bis-(3-ethylbenzothiazoline)-6-sulfonic acid (ABTS) radical with equal or greater than 5 mg of banana peel extract per ml of freshly squeezed juice. However, equal or greater than 10 mg banana peel extract per ml of orange juice produced undesirable in-mouth sensations and colour. Thus, banana peel has potential as a natural additive as free radical scavenger in orange juice.

The effect of banana peel flour (BPF), rice flakes and oat flour on the sensory acceptability of cereal bars using mixture design was investigated by Carvalho and Conti-Silva [25]. The lowest quantity of banana peel flour produced cereal bar with higher amount of rice flakes, chewiness and crispness. Formulations with intermediate and highest quantities of banana peel flour were darker in colour with higher banana aroma and bitter taste. The cereal bars were similar in hardness, adhesiveness, sweet taste and oat flavour. The feasibility of BPF in acceptable cereal bars as reported may diversify its use in new products for different market niches.

Maneerat et al. [26] extracted banana peel pectin (BPP) with HCl (pH 1.5) and water (pH 6.0) for 30–120 min at 90°C. The acid extraction produced 7–11% pectin (dry wt.) with 42–47 galacturonic acid (GalA), 57–61% degree of methylation (DM) and 17–40 kDa viscosity–average molecular weight (Mv). Lower DM with higher GalA and Mv characterised the water extracted BPP. The authors incorporated the BPP obtained from 60 min acid- and water-extraction into salad cream at 30% oil substitution. The result was a decrease in viscosity and lightness with a stable to cream separation during storage for 3 weeks. However, the salad cream containing water-extracted BPP had larger oil droplet size and greater extent of droplet flocculation. The full- and reduced-fat salad creams were similar in thickness, smoothness and overall acceptability.

Borges et al. [27] reported the quality of banana skin extract jellies. Based on the sensory and purchasing intention, the best formulations was obtained using a higher extract/sugar ratio (60/40) and lower pectin level (0.5 g/100 g) with the highest (20 ml) or lowest citric acid (15 ml) with scores for all the attributes ranging from liked slightly to moderately. The use of banana peel extract as an antioxidant is dose related. Equal or greater than 10 mg of extract per ml of juice is undesirable. Lower quantity of banana peel flour will produce consumer acceptable cereal bar and can be diversified into other niche products. It is possible to extract pectin from banana. However, the yield depends on the stage of ripeness of the peel.

Yangilar [28] studied the effect of green banana flour (GBF) on the physical, chemical, mineral and sensory properties of ice cream. The GBF affected moisture, acidity, fat, ash contents and viscosity positively, while meltdown, colour and overrun were negatively affected. Ice cream with 2% GBF received the highest sensory score.

Enrichment of fermented milk with green banana pulp (GBP) stabilises the probiotic strain, *Lactobacillus paracasei* LBC 81 during refrigerated storage [29]. The hue, chroma and colour difference of the fermented milks were less affected as the amount of the GBP increased. However, the GBP resulted in increase in syneresis and the occurrence of post-acidification during the storage period. Fortunately, these technological defects can be improved with the use hydrocolloids and has greater control of the fermentation process [29]. More than 70% of the panellists expressed mean values ranging from 6 to 9 on a 9-point hedonic scale for fermented milk with 6 g/100 g of GBP for all the sensory attributes. A sample is considered as having good acceptance when 70% or more of the individuals' express mean values on the 9-point hedonic scale of higher than 5 [29]. Green banana pulp (9 g/100 g) negatively affected the acceptance of the product due to the acidification of the product, thus the rejection related to flavour and overall quality. The authors concluded that the use of green banana pulp can contribute to the nutritional quality of the fermented milk due to its phenolic compounds, resistant starch and fibres, thereby impacting consumer health due to its probiotic and prebiotic effects.

Pork skin (PS)-green banana flour (GBF) gel (PS-GBFG) was produced from cooked pork skin at 80°C for 60 min, ground through a 3 mm plate and mixed with water and GBF in a ratio of 1:2:2 (PS:water:GBF) using a cutter until complete homogenisation. The gel was used as fat replacer in bologna type sausages [30]. The PS-GBFG decreased the fat content, did not affect the protein levels while it increased the resistant starch significantly. It also improved cooking loss and emulsion stability, 60% substitution did not affect the colour and texture of the sausage. Although the 60% substitution was effective for maintaining sensory quality, acceptable products were obtained with up to 100% substitution. Thus, PS-GBF gel was effective as fat replacer in Bologna type sausages.

GBF was reported to significantly improve the emulsion stability and cooking yield of chicken nugget compared to the control. This was attributed to the increase in viscosity by the GBF fibres which ultimately reduced shrinkage on cooking [3]. As a functional ingredient in chicken nuggets GBF served as a good source of dietary fibre with positive impact to microbiological quality and comparable sensory quality to the control [3].

Wheat flour was substituted with 10% banana pseudo-stem flour (BPF) in bread [31] resulting in significantly higher moisture, ash, crude fibre, soluble, insoluble and total dietary fibre but lower protein, fat and carbohydrate compared to the control. Presence of BPF resulted in a lower volume, darker crumb and lighter crust colour than the control. However, the addition of CMC improved the bread volume. All bread with BPF had greater total phenolics and antioxidant properties than the control with BPF and 0.8% CMC bread highest in overall acceptability and comparable to the control in overall acceptability. Saravanan and Aradhya [32] produced food beverage rich in antioxidants from banana pseudo stem (BPS) and rhizome (BR). The pseudo stem is an actively aerial stem with closely packed leaf sheaths that functions as a vascular bridge for the flow of water and nutrients from underground rhizome to banana leaves and bunch. The rhizome is a modified stem of banana plant that remains underground and bears the banana plant on surface and roots underground. The pseudo stem is obtained after removal of the surrounding leaf sheaths at harvest. The BR juice had higher total phenolic and flavonoid content with correspondingly higher antioxidant activity compared to the BPS juice. The ready to serve beverage prepared consisting of 25% BPS juice and 20% BR juice each with 15° brix total soluble solids and 0.3% acidity was the best based on the sensory qualities.

Unripe banana whose peel was green and the pulp not soft was washed, peeled and cut into 10 mm thick slices, steam blanched for 10 min, dried at 60°C for 24 h, milled and sieved into flour. The flour was mixed with water (10 g flour/3 ml water) and fermented for 24 h. The fermented slurry was used as starter for wheat bread using the straight dough fermentation method [33]. Substitution of the wheat flour with the fermented banana increased the crude fibre, carbohydrate and protein content of the bread. The wheat-unripe banana blend (90:10) produced better quality and sensory acceptable bread.

Ripe banana pulp is high in fibre, polyphenol compounds and simple sugars (61.1 g/100 g). Segundo et al. [22] reported the potential of ripe banana flour [RBF] (20 and 40% replacement) as sucrose replacer in cake formulation. The inclusion of RBF significantly increased the dietary fibre, polyphenols and antioxidant capacity to three-fold. However, the increased batter consistency resulted in a slightly lower specific volume and higher hardness contributing to the decline in consumer acceptability. This effect was minimised in layer cakes where differences in volume were only evident at higher substitution level.

Oliveira de Souza et al. [34] reported the replacement of fat (0–100%) in pound cakes and sugar reduction (0–50%) using green banana puree (GBP). Replacing fat with GBP resulted in changes in colour, slice size, compaction, odour, flavour and texture. The GBP was produced by washing 280 g of whole green bananas on the second stage of maturation (green with a trace of yellow) and cooking under pressure at 120°C for 8 min. The cooked bananas where peeled and the pulp (183 g) was mashed up for 5 min in a multiprocessor with 100 g water to achieve the texture of puree. Sugar reduction negatively affected the appearance resulting to a higher proportion of big alveoli, beige or dark beige colour, mild taste, and wheat flour flavour. GBP replacement and reduction of sugar increased lightness, colour saturation and hue of the crust. The authors concluded that it is possible to replace 25% of fat with GBP in pound cakes and to reduce 20 and 40% sugar in low-fat cakes with GBP with very little impact on acceptance and sensory characteristics.

Flour from whole (pulp and peel) overripe banana (OWBF) was used as an ingredient in muffin. Products with OWBF in 400 and 500 g/kg of total flour were highly acceptable with high dietary fibre (181.9 g/kg) and resistant starch (35 g/kg), a low total starch (57 g/kg and high simple sugars (714.2 g/kg of carbohydrates were glucose plus fructose). The muffin with OWBF is classified as an intermediate glycemic load.

10. Conclusion

This chapter shows the power of integrating data mining and network analysis techniques in discovering interesting trends in quality of banana fruit and peel, use of banana fruit in food and wine as well as the sensory acceptability of banana peel and flour in food products. Arabic gum and chitosan coating can greatly reduce wastage by extended storage for up to 33 days. Ripe banana pulp is high in fibre, polyphenol compounds and simple sugars (61.1 g/100 g). These studies highlight the potential of banana pulp in extruded, fried food products and wine. Ripe banana flour significantly improved the nutritional properties of the cakes with increase in dietary fibre, polyphenols and up to three-fold improvement in antioxidant capacity. Banana pulp flour, peel, pseudo stem and rhizome all have potential in consumer acceptable food products.

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Banana Nutrition – Function and Processing Kinetics covers the nutritional aspects of the banana plant and fruit. The book contains substantial scientific information written in an easy-to-understand format. The chapters include information on pharmacological aspects of banana; banana bioactives: absorption, utilization, and health benefits; banana pseudo-stem fiber: preparation, characteristics, and applications; banana drying kinetics and technologies; and integrating text mining and network analysis for topic detection from published articles on banana sensory characteristics. All the chapters contain recent advances in science and technology regarding the banana that will appeal to farmers, plant breeders, food industry, investors, and consumers as well as students and researchers. Readers will harness valuable information about the banana in controlling food security and non-communicable nutrition-related human illnesses.

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